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COLOUR VISION REQUIREMENTS IN DIFFERENT OPERATIONAL ROLES

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Colour Vision Requirements in Different Operational Roles

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COLOUR VISION REQUIREMENTS IN DIFFERENT OPERATIONAL ROLES

Papers presented at the AGARD Aerospace Medical Panel Specialist Meeting
held in Brussels, Belgium on 30 May 1972

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P r e f a c e

by

Colonel D. KÜRSCHNER, MC, GAF
Session Chairman

The papers of this session will deal with the question: of what importance is color vision for the various career fields of an Air Force. This is quite an exacting topic considering the manysidedness, and the ambiguity of the factors which make us see the world in color. Thus, physical, chemical, physiological and esthetical, and also practical aspects play a role in color perception as in no other sensory function. When assessing the ability and reliability of color perception, these aspects must retain their due value in order to avoid erroneous conclusions. Unfortunately this has not always been appreciated in the past. It is therefore not surprising to find an abundance of observations and a multitude of theories concerning color perception by man and its disturbances without giving an unequivocal explanation up to this date, how the eye makes us see the world in a variety of colors.

In particular an observer with a background in natural science will find it difficult to free himself from a predominantly physically oriented mode of reflection concerning color vision. It is only with effort that we can imagine that light and color, and also sound and smell exist only as sensations in the endogenous world of our body, and that only matter and energy exist in the exogenous world so that this world of ours is actually without color, sound, and smell. Almost of compulsion do we project sensations from the interior of our body to the exterior world. We find this separation into exterior and interior world generally very difficult and it is an extreme burden on the understanding of color perception. Under these circumstances it is almost logical that we should also commit the linguistic mistake of confusing property with sensation. We still formulate in the sense of the Greek philosophers of old, stating that this object is red, that one green and a third one blue, and thus we accord property to these objects which in reality they do not have. Thus, properties are only attached to these objects through our sensory perception. To be exact we would have to say that this or that object appear to us in one or another color, in order to also draw a linguistic line of separation between physical rules and sensory perception. This would articulate with much more clarity that color is no property of an object but the result of radiation phenomena in connection with the properties of its physical surface constitution.

When even a fundamental understanding of color perception gives rise to considerable difficulties, it is not surprising to find a substantial increase of problems when assessing the functional ability and reliability of color vision disturbances. Already "classics" in color vision testing such as HOLMGREN and NAGEL were faced with this problem. The multitude of factors releasing or influencing color perception, as well as the behaviour of abnormal trichromates, difficult to understand and to calculate as it is, have made it cumbersome from the very beginning to initiate and disseminate practical examination methods. Even up to this day so-called "Practical Color Vision Examinations" are considered unscientific. Moreover, color vision examination methods hitherto and presently applied have been and still are by no means tuned to conditions or circumstances under which color signals and color markings are seen in the open country. This applies to pseudoisochromatic plates of various systems, to the anomaloscope, and also to most of the color signal test lanterns. As is known pseudoisochromatic plates will only aid in establishing whether the examinee is color proficient or not. NAGEL's anomaloscope enables a good qualitative or quantitative diagnosis but will reveal little about the safe or unsafe signal perception of color deficient subjects. We must not overlook that in this context we are concerned with spectral colors respectively their compositions. Their display area and above all brightness neither correspond to the real signals nor do they consider color perception on part of paramacular and peripheral sections of the retina. Possibly the extreme brightness and saturation in which colors are presented in the anomaloscope are responsible for the release of the so-called abnormal contrast increases and other signs of fatigue among the color deficient, which would not be so under realistic conditions of color signal perception. On the other hand, hue, saturation and brightness of the signal are reduced through ground - glass - filters to a degree not even brought about by the most unfavorable visual meteorological conditions. All this contributes to a wide-spread uncertainty when deciding on careers of color deficient applicants and in turn has led to a point where any color vision disturbance is globally considered as being dangerous. The evidence for this opinion, however, does not hold water. In 1907 NAGEL has published a review of 6 railroad accidents and 6 accidents at sea allegedly caused by color deficiencies of personnel involved. A critical evaluation of these mishaps revealed that in half of the cases color vision had not been the cause owing to circumstances in which correct perception and discrimination of colors had no bearing at all. To this very date injustice has been done at least to the abnormal trichromate and especially to deuteranomalous when assessing their reliability in professions involving matters of traffic and communications, but also in the military field. Since 50% of the male population with inhereted color disturbances are abnormal trichromates, their acceptance in several career fields would constitute a tangible relief in the manpower situation. This problem, however, can not be solved only on the basis of theoretical knowledge or through one or another combination of examination methods, but primarily through an analysis at the place of work. Such an "On-the-Job-Analysis" would have to indicate type of color, location of color, the size of color area, the eye-color distance, the lighting conditions and the importance of the color at the place of work. It is hoped that the following papers will give an answer to this issue.

CONTENTS

Technical Evaluation

A session on Color Vision Requirements in Different Operational Roles constituted a portion of the Aerospace Medical Panel Meetings held at the Shell Building in Brussels from 30 May to 2 June 1972. Some 80 persons attended the session and 11 papers were presented. They covered the relationships between clinical and theoretical concepts of color vision and their relation to color vision testing, the description of color vision testing methods in use, and the application of color vision testing results to practical situations. These papers and the questions and remarks in the discussions which followed devoted special interest to the problem, "to what extent is color vision required in the activities of flying personnel, ground personnel and personnel in other aviation operation career fields." The majority of the attendees were of the opinion that:

1. Certain types of inherent color vision deficiencies (for example, mild anomalous trichromats) can no longer be considered as absolutely incompatible with flying activities and flying safety. This seemed to be justified by "in-flight" observations, pragmatic color vision testing, on-the-job analyses and the fact that not one aviation accident has ever been documented as having been caused by a color vision deficiency of the pilots involved.

2. In a considerable number of military aviation specialties (air traffic controller, mechanics, crew members, etc) special emphasis is not placed on normal color vision as a physical requirement. This is due to the fact that color signals, or color markings are either not the sole source of information or they are not employed at all, (for example a radar scope, black and white instrument display, etc.) However, due to the redundancy of information displayed, or the type of display, normal color vision may be mandatory for such career fields.

3. If comments 1 and 2 above are accepted as operationally valid then subjects showing a color vision deficiency diagnosed by conventional pass/fail screening test methods may subsequently be accepted as a student pilot or crew member if able to pass a color lantern test. The color lantern tests being less severe enable the mild anomalous trichromat to pass, while failing the severe anomalous trichromat and the severe dichromat. This technique permits a color defective individual, trained pilot, crew member, or even an applicant to be considered as "color safe". Test like the Farnsworth Lantern and the USAF Color Threshold Test have been operationally validated and proven to have this discrimination ability.

4. For the time being one of the best methods for screening subjects to determine normal color vision is to employ pseudo-isochromatic tables, such as the original by ISHIHARA. This test, the Tokyo Medical College series and similar tests are excellent pass/fail test to establish normal vs non-normal. On the other hand, they are not good predictors of severity of anomaly or type of anomaly.

5. A standardization of color vision testing methods between the NATO nations does not appear feasible at this time because of the general lack of unanimity about the relative merit of test methods, the problem of differences in personal experience and training among professional staff, and also the problem of differences in organization. The variability associated with the management of physical evaluation of applicants and flying personnel is one of the key issues. For example, the control provided by having all medical exams performed centrally at one facility is necessary for the quality control of certain color vision testing techniques. Moreover it depends on the number of testees and on the battery of color vision tests available and feasible. Some are prohibitively expensive and require considerable scientific skill and ability to administer. Decentralization of physical examinations prevents the optimum and necessary control of color vision evaluation. This problem alone defeats standardization.

6. Dichromats (those color defectives totally red-green blind) and extremely abnormal trichromats (i.e., borderline cases who have nearly as severe color vision defects as the red-green blind dichromats) should be excluded from aviation activities that require any degree of color perception. Until more information is available there is a high risk that this level of color defect vision could lead to judgement errors and consequently to erroneous actions compromising mission accomplishment and flight safety. This type of color defective is unable to pass the color lantern tests (Farnsworth Lantern).

7. Even though color coding as a means of information display is technically easy to give and easy for the color normal to perceive, aircraft designers and manufacturers should be required to devote sufficient attention to color vision so that information displays are not color dependent. If this is done color coding will not become the only source of information for those who must control an aircraft or perform maintenanes duties on it. So, it may be expected that almost 50 % of color deficient subjects, especially mild deuteranomalous ones, could be successful in aviation careers for which they are otherwise qualified, e.g., by extraordinary psychomotor skills, high motivation, and lack of motion sickness sensitivity, etc.

THEORETICAL ASPECTS OF COLOR VISION

by

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SUMMARY

Our present understanding of color indicates that the classical theories of color vision, the three color receptors of Young-Helmholtz and the opponent colors type of information processing postulated by Hering are both present in the human visual system. This mixture accounts for both the phenomena of color matching or hue discrimination and such perceptual qualities of color as the division of the spectrum into color bands. A discussion will be given of the detailed functioning of the cells in the visual system, especially within the retina and the relation of this function to color perception. Some details of how this knowledge can aid in understanding the role of color vision in operation situations will be mentioned.

1. INTRODUCTION

Our understanding of color vision has been hampered since its beginning as much as it has been helped by a fundamental dichotomy between the two methods of approaching the problem. The first approach is that exemplified by the Young-Helmholtz trichromatic theory,(27,9), the other is its apparent antagonist, the Hering (10) [and possibly Goethe (3)] opponents colors theory. The followers of Young and Helmholtz have become dominant in recent years. Their method of analysis leans heavily on theoretical physics. Thus, they have concentrated more on the stimulus, whereas the followers of Goethe, especially Ewald Hering, have been psychologically oriented. They have concentrated rather upon the sensations.

Physical School--The Stimulus

The Young-Helmholtz theory is mathematical in nature. In it three pure spectral hues are necessary to match any other spectral hue or combinations of spectral hues. From this it has been inferred that there are three different types of color receptors in the retina. Although no more than three types are needed, this approach does not rule out the possibility that there are more than three. Neither does it define the three receptors that are needed. The names of many physicists famous for other work can be found in the list of those who have made contributions to this aspect of color vision. An early worker was Clark Maxwell (17), another was H. von Helmholtz, already mentioned (9), and more recently we find Erwin Schroedinger (18). One might think that such men as these who have solved so elegantly problems in electromagnetic theory, thermodynamics, and quantum mechanics, respectively, would have little difficulty with such a minor biological problem as color vision. Although Maxwell's contributions did much to aid in research, they did little to foster understanding. He furnished a way of plotting data and a machine, the anomaloscope, with which much research has been done. But as far as elucidating the mechanisms of color vision nothing really definitive about the mechanisms of color vision has come from these approaches. The main problem posed by the physical school was to find a transfer function for color matching by the entire visual system. The input conditions are the physical stimuli, the output is the acceptance of these by the subject as matching or not matching colors. Thus, only three spectral colors are necessary to match any other color in hue, intensity, and saturation. This school is mainly concerned with what I term "hue discrimination", that is, the discrimination of one spectral wavelength from another. The physical aspects of the stimulus are emphasized in the formulation of a model for the visual systems.

Psychological School--The Sensations

The psychological school, on the other hand, has to a large extent, ignored or confused the physical aspects of the stimulus and have been concerned with color as color. That is, they asked: why do we perceive the spectrum as divided into bands of different colors? Why are the blue or green or yellow, or red broad portions of the spectrum not, oddly enough, of equal width or of equal quality? For example, yellow is the narrowest portion of the spectrum. Also, the spectral extent of these color bands is not completely arbitrary nor does it seem to be learned.

Recent Development

For the first half of this century the physicists and the psychologists devoted large portions of their time calling each other names and presenting decisive arguments to prove that the other's approach is wrong. Although the modern methods of research do not give an interpretation of the data that leads to a clear and absolutely final description of the mechanisms for color vision in man, much has been learned in the past few years. A summary of that information together with a discussion of the problems that are left at least indicates the broad outlines of how color vision works. Certain things can be understood in an operational way and many theories can now be shown to be impossible.

Difficulties of Trichromatic (Young-Helmholtz) Theory

The Young-Helmholtz theory in essence shows that at least three color receptors are necessary. In mathematical terms however, they cannot be shown to be sufficient; i.e., more than three may be present and the system will accomplish the same thing. Convention has settled on a blue, a green and a red receptor.

Much of the arguments within this school have been concerned with whether there are only three and also which particular three they are. However, neither position can be established by the kinds of experiments that had been done prior to the last decade. The possibilities and difficulties of this approach were summed up many years ago in an article by Selig Hecht (8).. He examined the action spectra of the three photopigments that had been postulated by previous workers in terms of which would produce all the known phenomena of color or, as I say, hue discrimination. Figure 1 is an illustration of how Young's three color receptors would be plotted. Figure 2 shows three receptors postulated by some of the more recent followers of Helmholtz. The various wiggles in these curves are important to explain the various anomalies in the equations governing hue or color mixing. In Figure 3 are the spectral sensitivities of the three color receptors as postulated by Hecht himself. He has a green, a red, and a blue (which he calls violet). I think that this figure was put forward somewhat tongue-in-cheek, as I have heard that Hecht had a magnificent sense of humor. This figure indicates an extent to which the statement made above is true; the Young-Helmholtz theory requires three color receptors but does not specify what they are to be. It is true that this theory gives some restraints upon them in that if any two action spectra are picked, the shape of the third is determined by its peak wavelength. Hecht's article pushes this theory to the extreme. It is likely that in this reproduction of Hecht's figure the curves cannot really be seen to be different, yet they are. They are different enough such that if three such pigments did exist and were in photoreceptors they would furnish all the data for hue discrimination required by the Young-Helmholtz theory and its more modern modifications. Yet the error in all our experimental measurements is such that we could never find these curves as separate.

Difficulties of Classical Opponents Colors Theory

The psychological approach on the other hand, is confined to the problems connected with the sensation of color and with color defects. The most famous exponent of this system is Hering. He postulated mechanisms within the visual system which would produce a fundamental antagonism between the colors red and green and the colors blue and yellow. These he considered as opponent pairs with a third pair based on the opposition between black and white. This theme was interpreted by the physical school that there would be six receptors--a red-green pair, a blue-yellow pair and a black-white pair. However, that is not necessary for the theory, nor was it postulated exactly in that form by Hering. His intuition may have been a little better than that of his modern followers. The theory itself, until quite recently, had become quite declasse. It was held to by only a few psychologists and ophthalmologists who had a broad irrational streak running through their thinking.

In spite of its increasing neglect the psychological approach accomplished much of what its originators had set out to do. That is, it furnished a more or less coherent explanation of the various forms of color blindness and dealt with the problem of why color names rather than just having arbitrary divisions of a continuous spectrum. Also, in a qualitative way it was able to furnish an explanation of the necessity for color contrast phenomena. Although the physicists had already quantified these phenomena they have furnished no explanation for the necessity of them. However, the two areas in which the psychological theories were most successful was in explaining why there were negative after-images. That is, why the after-image was the so-called complimentary or opposite color to the stimulus color. Certain visual illusions, particularly those concerned with the confusion between movement and color, such as Benthan's top were also on a more rational basis. The Young-Helmholtz theory hypostulated a so-called labeled line running from each of the three classes of color receptors back to the higher visual center. There the information about the stimulus was decoded in a simple fashion. It was the intensity of the stimulus acting on a certain color receptor. A simple combination of the three intensities (one from each of the three classes) defined the hue (wavelength) and intensity of the stimulus. Obviously in such a system there is no simple way to confuse this information with that of motion. Rapidly changing light upon the receptors will never be seen as colored when there is no color information in the original stimulus.

However, the psychologists had already formulated a rather elaborate code for each nerve cell, that is, that each cell carried positive information about one color and negative about another. Thus a rapidly changing stimulus could introduce some confusion into the color interpretation as the code itself had built in ambiguities.

Limitations of Classical Methods: Early Attempts in Neurophysiology

Neither of these approaches were sufficient to define the exact function of the color vision system in man. Neither could tell whether behavioral experiments upon animals could show if their vision was identical with or if different. how different from human color vision. That is enough of the history to bring us to the modern physiological research. Suffice it to say that as might be guessed by an historian, both sides turned out to be wrong and both right.

Such roughly was the situation up until about 1954. From this date the modern approach to color vision can be said to start with the experiments of Gunnar Svaetichin (20). Another physiologist who aided in developing our methods of attack to establish the current theories of hue discrimination and color perception is Ragnar Granit (5). They tended to carry over their earlier loyalties into the interpretation of their data, Granit to Young-Helmholtz and Svaetichin to Hering. With this as background it is now appropriate to examine what has been learned in the past few years about the detailed functioning of the various parts of the visual system, especially with respect to color vision.

2. THE MODERN APPROACH: OPENING THE BLACK BOX

Although presenting this material from a histological standpoint would be of great interest the constraints of space make it more reasonable to present the logical sequence. As such we will start with the image upon the retina and show what kinds of receptors there are, then how they are stimulated. Next the information flow will be followed back through the intervening neural layers to the ganglion cells through whose axons all information passes back to the higher visual centers. Such parts of the higher visual centers as are known will be discussed with a consideration of the final problem of perception itself of the color in the stimulus.

The pattern of color upon the retina can initially be con-sidered to be made up of points of light small enough to stimulate single receptors. Although the optics of the eye even under the best conditions do not quite reach the ideal situation for maximum acuity, few physiological experiments are done under such stringent conditions. Thus no errors will be introduced into the interpre-tation of the experiments at this point by assuming that the optics are perfect. The first element to be considered, then, is the receptors, what they are and how they respond to the stimulus with respect to its wavelength and its intensity.

The duplicity theory of vision is of long standing; that is, that the rods are responsible for night or scotopic vision and the cones for daylight or photopic vision. It is these latter cells, the cones, which are responsible for normal color vision.

A. Receptors

The classification of receptors and the analysis of their function depends upon three types of experiments. Two of them involve direct measurements on the cones and the third infers the cone properties from electrophysiological recordings from cells further back along the visual pathway. These latter experiments are done under conditions in which the variation of the electro-physiological response with the variation of stimulus parameters is thought to be due to the characteristics of the receptors themselves . One of the direct approaches is the measurement of the absorption spectrum of the visual pigment in a single cone or rather the difference in the spectrum after bleaching. The other is to put microelectrodes in single receptors and measure the variation of their electrical polarization as a function of both light intensity and wavelength. The measurement of the difference spectrum of a single cone is simple in conception. One merely puts the isolated cone into a microspectrophotometer and measures its optical density as a function of wavelength before and after a bleaching light. In practice of course, it is not so simple. These cells are quite small and the amount of pigment they contain is small. Therefore the light used to establish the initial or unbleached spectrum must be very dim. Otherwise the first exposure of light at the wavelength used will bleach all of the pigment, leaving none left to be measured by other wavelengths. In this case the entire spectrum could not be plotted on a single cell. However, these technical difficulties have been overcome and similar results have been obtained by many independent groups: Marks (16), Wald and Brown (25), Liebman (13), Harousi (7), and others. All find that there are three types of receptors whose absorption peaks roughly correspond to the blue, green and red receptors. In Figure 4 some typical curves from these experiments are illustrated.

The use of the second direct technique, that of probing with electrodes into the single cones gives comparable results. Here again a number of investigators have confirmed the original results. The most complete set of data is that from Tomita and his co-workers. In the cones a steady hyperpolarization (that is, an increase in the negativity of the cell with respect to the outside) is recorded as the intensity of the stimulating light is increased. The sensitivity to different wavelengths can also be measured. This is shown in Figure and it agrees with measurements made on the difference spectra of cells from the same eye. This indicates that the difference spectrum of the cell is also the action spectrum. The magnitude of the stimulus that bleaches the pigment in the photoreceptor cell then, is the same as that which is responsible for stimulating the cell into electrical activity.

The third or indirect approach will be described in greater detail below. Briefly this consists in recording from other cells in the retina in order to see just how they are connected to the cones, then attempting the stimulus is adjusted that the response of the cell recorded from is dependent only upon the characteristics of the cones. That is, as the wavelength is varied the stimulus is presented in such a fashion that the interaction of the cone with that particular cell is the same. Some of the interactions are quite complex in the retina and only under certain conditions can such inferences about cone function be made.

The output from the receptors appears to be proportional to the amount of hyperpolarization induced into the cell by the intensity at a given wavelength of the stimulus. The output of the receptor cell goes to bipolar cells, horizontal cells, and Mueller fibers. These in turn interact with the amacrine cells. They all finally converge upon the ganglion cells at which point the message is integrated sufficiently to form the basis for all further activity by the visual system. That is, all information passing from the receptors back to the visual cortex must pass through the ganglion cells. The ganglion cells furnish a logical place to look for information which will actually be used by the nervous system in deciphering the visual stimulus. However some details about the function of those intermediate structures will be necessary as a background for an examination of the ganglion cell activity.

B. Intermediate Structures

It is sufficient to say that in all the structures intervening between the receptors and the ganglion cells that no nerve impulses are seen in any regular fashion. Most of these cells appear to respond with graded changes in potential much indeed as you might expect from an analog computer. Although there are many, many micro steps with the release of separate transmitter molecules by each cell at its synapses, the noise in the system is such as to probably effectively block out most such discrete variations in the final response. One possible exception is that due to the so-called quantum bumps in the receptors. In scotopic vision the stimulus of a single quantum of light can produce a single quantized electrical response in the red receptors. However at photopic light levels such effects are not seen in the cone receptors.

1. Opponent color responses

Figure 4 shows typical recording from a horizontal cell. Records of this type triggered off the modern interest in color vision, when they were obtained by Svaetichin (20) in the middle 50's. In these cells (later identified as horizontal cells) that the magnitude of the potential varies with the wavelength is not unexpected and that the cell is hyperpolarized or depolarized by light is not in itself surprising. However, that it should both hyperpolarize and depolarize is startling. Here we have a suggestion that retinal coding of color is similar to the description in Hering's color vision theory. In those horizontal cells, as shown in Figure 5, there is hyperpolarization at one end of the spectrum and depolarization at the other end. Some cells have even more complex curves such as the triphasic one in Figure 6. These

curves can be shifted around by color adaptation at one end of the spectrum or the other. This shows that the response of this cell is composed of the inter-action between two separate groups of receptors, each group of which is acting independently. It is only recently that all the different types of cells involved have been positively identified by staining technique.

2. Objections to opponent color responses

For a long time many investigators believed that the horizontal cells, which were the first type to be identified, were not along the main line of information flow. It was supposed that the responses of these cells were formed by the addition of the extra-cellular current flow from two or more cell types which were on the main line of information flow. In this case it is supposed that there would be two cells, possibly bipolar types, lying close to each other, each carrying information from a different class of cones. In this case the bipolar cells were considered to have simple monophasic responses as a function of wavelength, some depolarized, others hyperpolarized. A third cell, this time an horizontal cell (possibly glial in nature) lying in between the bipolar cells could reflect the activities of these two types by summating the external current flow from each (6).

One might suppose that the two or more classes of bipolar cells in close juxtaposition to each other might each represent the activity of a different class of receptors, that is, one bipolar cell for example might be hyperpolarized by the red end of the spectrum and its neighbor depolarized by the blue end of the spectrum. The horizontal cell lying in between would summate these activities and (as the external currents though would have the opposite sign) be depolarized by red, hyperpolarized by green. However, the crux of this theory was that this summated or opponent colors information from the horizontal cells was not passed on to the deeper layers in the retina. This interpretation of the data was compatible with the Young-Helmholtz theory. A ganglion cell, for example, would receive its input from only one type of cone (or even, in the foveal region, a single cone) as was axiomatic in an analysis based on the Young-Helmholtz theory. A variation in this theory viewed the horizontal cells as glial in nature. The glia regulated and modified the neuronal activity by slow and long lasting setting of the level of excitability (2) (14).

However, now more is known about cell types other than the horizontal cells. All types may upon occasion display qualitative differences in behavior as a function of the wavelength of the stimulating light. Thus the responses of most intermediate cell types resemble those already described for the horizontal cells. This departure from the Young-Helmholtz model is even more apparent when the responses of the ganglion cells are examined.

Before we pass on to the ganglion cell characteristics it should be noted that the responses of the horizontal cells, the bipolars, the amacrines and others, show in addition to the color coding a high degree of spatial organization (17a). That is, each cell behaves as if it is connected to receptors in a large area of the retina. Perhaps in the foveal region in primates only a few cones are connected to one bipolar. It is in no way evident that each bipolar cell is a private line for a single foveal cone. Indeed it seems to be that there are at least four cones to each bipolar, and each cone is connected to more than one bipolar. The receptive fields of these cells (a large portion of the retina connected to each) indicate convergence of receptors upon a single cell. The implications that this convergence has for form perception and visual acuity are beyond the scope of this paper, and must be considered in detail at some future time.

C. Ganglion Cell Response

All responses leaving the retina originate in the ganglion cells, thus, all information upon which the higher centers act is based on the ganglion cell responses. The ganglion cell output is in fact the raw material for perception itself.

1. Color components of ganglion cell responses

In the ganglion cell responses is the final and irrefutable evidence that a type of sensory coding based on some m... ation of the Hering opponent colors theory is an integral part of the vertebrate visual system. Figure 7 illustrates this point. Here a ganglion cell has some ongoing (or spontaneous) activity in the dark; when red light is used as a stimulus it is stimulated to higher levels of activity. When green light is used as a stimulus it not only is not excited but rather is inhibited. This is shown by the suppression of the background of spontaneous activity. This pattern of responses, of course, parallels those of the horizontal cell where a hyperpolarizing response of the horizontal cell represents inhibition of the ganglion cell and depolarization of the horizontal cell represents the excitation. In the ganglion cell also it is evident that these two influences upon the cell represent an algebraic summation. The red and green components of the response, to name an example, can be manipulated separately by light adaptation and other means.

2. Spatial aspects of ganglion cell responses

The ganglion cell responses also reflect the high degree of spatial organization in the responses of the earlier layers of the retina. Figure 8 shows the receptive field of a ganglion cell in the retina of a goldfish. It should be noted that there are two zones with a pair of opposed influences in each. That is, the red information channel exciting the center which is opposed by a green information channel inhibiting the center. The red off response in the periphery opposes the green on response in the periphery and the red on response in the center. A similar situation exists for the green.

The peripheral portion of the receptives for ganglion cells in the primate retina or human retina have not been worked out in as much detail but it is likely that similar types of organization will be found for them. Most of the work done to date in primates has been on form and motion detection and has largely ignored the interactions between color and form or motion perception. It is obvious, however, even from the few experiments that have been done so far, that the ganglion cells in the primate system have complex receptive fields. Color is certainly a large part of the complexity. Many more experiments

are in progress now and a more complete scheme will be available soon.

The information passes through the lateral geniculate body to the cortex, the tectum, and into the various association centers. Even the fragmentary knowledge at the present indicates that much more elaborate forms of coding and decoding are taking place in all these areas. Although we have many isolated facts we do not have sufficient data to give us a complete comprehensive theory.

3. PRESENT CONCLUSIONS TO BE DRAWN FROM CURRENTLY AVAILABLE DATA ON THE VISUAL SYSTEM

The obvious conclusion to be drawn is that the visual system represents a blend of the Young-Helmholtz trichromatic theory of color vision with that of its seeming mutually exclusive antithesis, the Hering opponent colors theory. It is not surprising that previous experiments, in some cases, supported one theory, in other cases the other. Indeed, both theories are somewhat true. There are three types of color receptors and they are coupled together in opponent pairs. This coupling occurs very early in the system. One might speculate at the present time as to what implications could be drawn from such a blended system. For example, let us look at the message from the ganglion cell in terms of what might be perceived from it.

A. Constraints Placed Upon Perception by the Ganglion Cell Responses

The early summation or interaction of responses from the different classes of color receptors seems to suggest that information about relative intensities of each of the color components is passed back into the central nervous system. Consideration about absolute intensities is not present in a straightforward way. This situation probably underlies Grassmann's law of color matching. A color match made under one set of background lighting conditions will hold even though the background conditions are changed. This is true even though the colors are not perceived as the same as the original pair, i.e., the name of the color might change.

In our earlier analysis we have ignored the role of the rods. Recent experiments indicate that all ganglion cells are connected through intermediate cells to cones (4). Thus any information reaching the higher centers from a rod receptor must pass through a ganglion cell which is also connected to a cone. A complete rod input of course is gray as in night vision. Although the Purkinje shift also depends upon rod function, for the moment we will overlook this and concentrate upon photopic conditions when normally we do not expect rod function. The evidence at the moment suggests that when the cones are stimulated sufficiently strongly they prevent the signal from the rods from reaching the ganglion cells. It is tempting to speculate at this time about the situations where colors are desaturated, that is, a large amount of white added with the spectral stimulus. Possibly the opponent pairs of cones have their response balanced in such a way that they cancel each other. This allows the rod response to leak through to stimulate the ganglion cells. As the rods appear to be connected to the ganglion cells in such a way as to simulate a balanced cone input, then any rod input would seem to be a desaturation of the stimulus color. This would be the situation when many of the cones are equally stimulated as by any broad band stimulus, so-called white light. It is possible that large numbers of rods would also contribute to the signal to determine perceived color. Also this could be why a saturated color next to an unsaturated one tends to make the unsaturated color look more saturated. The saturated color would have the effect of decreasing rod function generally; that is, over wide areas of the retina, which would then indicate higher saturation values for all the colors in the visual field.

B. Relation of Physiological Data to Other Current Theories

Several other theories of color vision have been popular in the past few years; noticeably the dominator modulator theory of Granit (5), the unireceptor theory of Biernson (1), and the retinex theory of Land (12). The dominator modulator theory for many years used the best physiological data available. However in many ways it was a misinterpretation of that data in an attempt to reconcile the data with the Young-Helmholtz theory of color vision. Such obviously is not possible as more data became known. The data that was collected by Granit has, in fact, been used as a bolster for our modern theory blending the Hering opponent colors theory with the Young-Helmholtz trichromatic theory. As mentioned before the techniques perfected by and questions raised by Granit have formed the basis for more modern experiments leading to the current theory.

Biernson's theory was one born after its time. He postulated a single cone type which by a scanning method had different spectral sensitivities. Although mathematically possible, it is inconsistent with the microspectrophotometry and electrophysiology of single cones. At present it is completely untenable as a model for reality. As a theoretical model for a color vision system in an unknown animal it would certainly work and be equivalent in overall function to the systems that we do know.

In its broadest sense Land's theory emphasized the relative aspects of color. It is really in a direct line from Goethe's theories, where everything depends upon border contrast, overall luminances and in background colors. Land emphasizes the deviations in actual color perception from what would be expected from a purely physical analysis of the stimulus. The theory itself is not complete nor novel as several articles, notably those of Judd (11) and Walls (24) have shown. However, Land's insistance upon the perceptual aspects of color should not be overlooked. It is certain that future research in color vision will concentrate heavily on the types of phenomena that he has shown so elegantly. These are mostly related to color contrast and the difficulties in relating perceived color to the physical stimulus.

The simplest way to understand color vision at present is probably to ignore all of the previous literature in the field. Color vision is a field in which too much has been written. The student is drowned in a sea of literature. One can only hope that in the future, a definitive exposition will be written describing the detailed working of the visual system together with a simplified summary of the principles upon which it operates.

E. Implications of Modern Theory for Defects in Color Vision

The foregoing analysis shows that many loci exist in which structural or functional defects cause disturbances in color vision. Depending upon the severity of the defect and its location, individual color perception may deviate from essentially normal to completely lacking, with many small gradations in between. For example, a reduced number of one type of cone would cause an emphasis of the colors depending on the signals from the other types. Possibly some false color information can also come from the rods as has been explained above. However, the perception of colors can easily be separated from the epreception of form. Not all types of cones seem to be used in visual acuity under usual circumstances. Thus, visual acuity may be normal when the color sense is quite reduced. There are few blue cones and they seem to report color rather than form. Blue light would have the lowest visual acuity associated with it. Yellow is the best for visual acuity and for intensity matches.

The color defects will to a large extent fall into the scheme proposed by Hering. Green and red perception will disappear together, as would blue and yellow. However, the luminosity response will also be affected if one of the classes of cones is missing. Such seems to be the case for protanopes who lack sensitivity in the yellow red regions of the spectrum.

F. Possible Variations in Normal Color Vision Resulting From Stress and Fatigue

In general the operational demands upon normal color vision are quite gross. They do not involve sophisticated differences between hues or saturations. Of course where color camouflage is involved some very sensitive individuals may perform much better than those with so-called normal color vision. Those in turn are at an advantage over color defectives. However, it should be expected that in such a finely balanced system as the one that mediates color perception, stress, fatigue, and other deleterious effects resulting from variations in the environment will affect color vision. Perhaps these variations in color vision only show up in tests which reveal the detailed inner balance of the system. Color illusions, such as Bentham's top, depend upon a confusion between types of information within the visual system, in this example, that of motion information with color. Any shifts in the operating characteristics in the various parts of the system will change the perception of this type of illusion. Adverse conditions can also influence the recognition of colors and the success of a particular operational mission may be impaired. For example, if low intensity (and low saturation) red and green were confused then it would be difficult to judge whether an airplane is approaching or leaving, as port could not be told from starboard. When more is understood about the visual system other examples can be predicted. Perhaps in the future our understanding of what demands and limitations can be reasonably placed upon color vision will be more complete. Now we mainly find the limitations after an accident points up some particular quirk in the perception of colors.

4. CONCLUSION

Our present understanding of color indicates that the classical theories of color vision, the three color receptors of Young-Helmholtz and the opponent colors type of information processing postulated by Hering are both present in the human visual system. This mixture accounts for both the phenomena of color matching or hue discrimination and such perceptual qualities of color as the division of the spectrum into color bands. A discussion has been given of the detailed functioning of the cells in the visual system, especially within the retina and the relation of this function to color perception. Some details of how this knowledge can aid in understanding the role of color vision in operation situations are mentioned.

5. ACKNOWLEDGEMENTS

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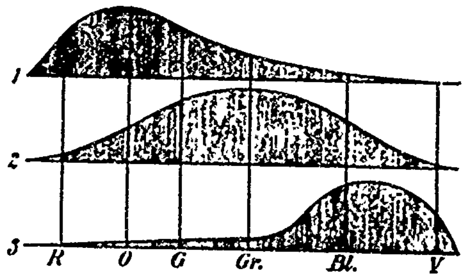

Figure 1. The spectral sensibility distribution of Young's three primaries as interpreted by Helmholtz. R = red, O = orange, G = yellow (gelb), Gr = green, Bl = blue, V = violet. Adapted from Hecht (8).

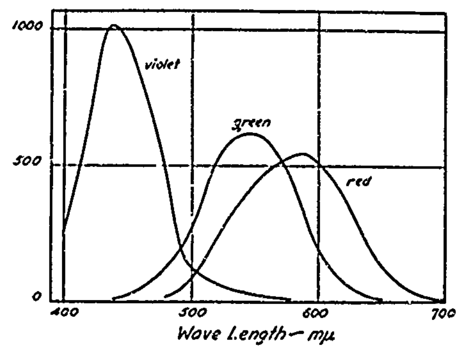

Figure 2. Relative sensitivity of standard receptor curves from the colorimetry committee of the Optical Society of America adapted from Troland (22).

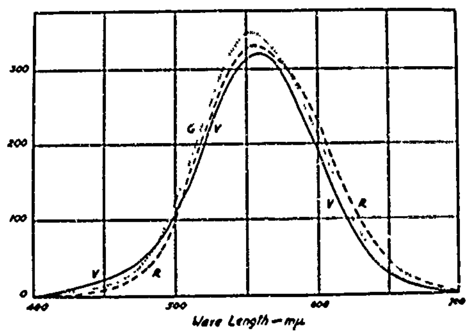

Figure 3. Spectral distribution of the primary excitation curves (action spectra) of the receptors as suggested by Hecht (8). R = red, G = green, V = violet (blue). The development of Thomas Young's three color primaries is shown here in its most extreme form.

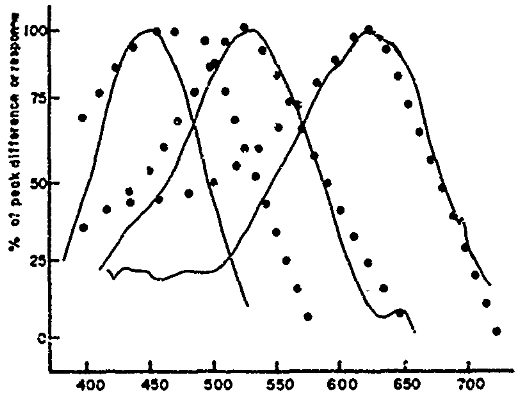

Figure 4. Different spectra and action spectra for cones in goldfish retina. The different spectra (solid lines) are based on the data of Marks (16). The action spectra (solid circles) is based on the recordings from single cones with micropipettes by Tomita et al. (21). These data indicate that there are three cone types with widely spaced spectral peaks. Similar difference spectra have been obtained from human cones.

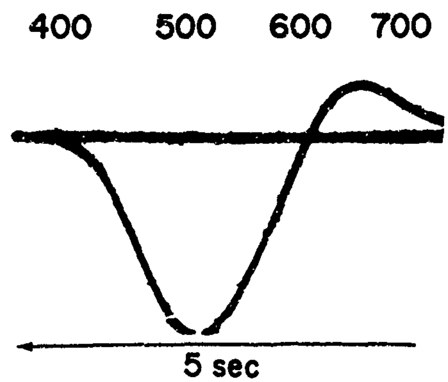

Figure 5. Potentials recorded from a horizontal cell in the goldfish. Up in the diagram indicates positive at the recording electrode. The horizontal trace indicates the resting level of the cell in the absence of a stimulus. The sweep direction of the wavelength change and its duration are indicated by the arrow at the base of the record. The peak to peak height of the response is approximately 4 mV. The ratio between the hyperpolarization and depolarization can be altered by the chromatic adaptation [after Wagner et al. (23)].

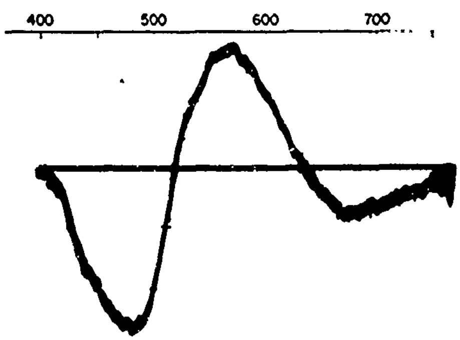

Figure 6. Trichroma response recorded from horizontal cell in the goldfish retina. Peak to peak value of the response is approximately 9 mV. The horizontal line indicates the resting level of the cell in the absence of a stimulus. The resting level is approximately 30 mV negative to the surface of the eye. The other details are the same as in Figure 6 [after MacNichol et al. (15)].

Figure 7. Variation of response of a single ganglion cell in goldfish retina with a change of stimulus wavelengths. A constant intensity stimulus (4.5×10^{-2} μW/cm^2) was used. The wavelength of stimulus in nanometers is given beside each record. The duration of stimulus is indicated by a step in the signal trace at the base of each record and was approximately one half a second. Impulses occurring before the end of each record are spontaneous in origin. The variation in the height of the spikes probably reflects the relative polarization or depolarization of the ganglion cell at the time the spike was initiated. It should be noted here that the off response (or increased frequency of impulses at the cessation of light) is intimately connected with the suppression of activity during the time that the stimulating light exposure. There is always a noticeable latency between the stimulus and the response for both on and off [after Wolbarsht et al. (26)].

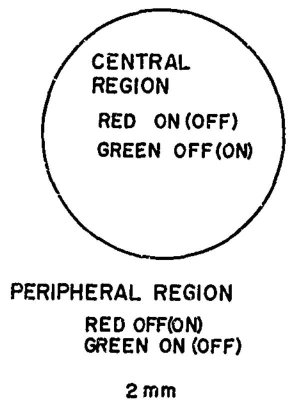

Figure 8. The spatial distributions of color sensitivity of a typical ganglion cell is mapped on the surface of the retina. This receptive field plot shows central and peripheral zones. These follow the selection rules given in Spekreijse et al. (19). Two types of ganglion cells responses are shown, with and without parenthesis. The responses within the parenthesis are always paired with each other, but are never found in combination with those not in parenthesis. In each of the two areas complete summation is to be found for each of the different influences. Not all of these responses are present in each of the ganglion cells. A blue receptor (not shown in this diagram) is also present in some of the more complicated kinds of fields. Presumably these spatial distributions of sensitivity are derived from the spatial distribution of such complicated intraretinal horizontal cell responses as shown in Figure 6.

Practical Aspects of Color Vision and its Disturbances

by

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SUMMARY

A number of specialities of the German Air Force except Flying Personnel were assessed to determine the extent of color vision required by the personnel involved. It could be shown that only for the activities of the Telephone Technician and Telephone Construction Technician is normal color vision mandatory.

Literature on color vision in man shows that the problem of color perception in training for and performance in an occupation has hardly been covered. In particular there are no indications which color information must be perceived in the separate branches of activities and which color information is important or of less relevance. This is very surprising inasmuch as an on the job analysis of these problems may be accomplished without great experimental efforts or equipment. In a field study I have assessed nearly all specialities of the German Air Force except Flying Personnel using the following criteria:

1. What color signals or markings must be perceived in different Air Force specialities?
2. Are color signals and markings the only source of information for the activity in question?
3. Are there pieces of information in the respective activity which replace a color signal or a color marking or supplement it to such an extent that the information may be perceived correctly?
4. Can it be said in consequence that color deficient soldiers may be assigned to the respective speciality without any hazards?
5. We have accepted the findings of a publication by CIBIS and HUCK in 1949 as a physiological criterion. The data presented by these authors show the perception threshold in the normal trichromate to be at a visual angle of 62,5 angular seconds and in the abnormal trichromate at 105 angular seconds.(1)

When dealing with the problem how color deficient persons perform I have the advantage of being deuteranomalous myself. On the anomaloscope after NAGEL my value is 20/15, when using the pseudo-isochromatic plates after ISHIHARA my error score is approximately 7, and I also have a moderately anomalous alteration of color contrast. Under these aspects the following air force career fields were studied (for illustrations see appendix):

A. SIGNAL AND TELECOMMUNICATIONS
   1. Switchboard Operator
   2. Teletype Operator
   3. Morse Code Operator and R/T Operator
   4. Telephone Technician and Telephone Construction Technician
   5. Teletype and Morse Code Technician

B. RADAR CONTROL SERVICES
   1. Radar Aircraft Warning Service
   2. Radar Forward Air Controller
   3. Radar Anti-A/C Rocket Control Service
   4. Radar Air Status License
   5. Radar Operation License
   6. Air Defense License
   7. Air Defense Control License

C. MILITARY AIR TRAFFIC CONTROL

D. ELECTRONICS WARFARE

1. Radar-Approach Control
2. Radar-Ground Control Approach
3. Tower Controller
4. Electronic Reconnaissance
5. Communications Intelligence Operator
6. Radar Technician

E. AIRCRAFT MAINTENANCE

1. Aircraft Mechanics
2. Engine Mechanics
3. Aircraft Electricians
4. Aircraft Electronic Personnel
5. Instrument Mechanics

A. SIGNAL- AND TELECOMMUNICATIONS

1. Switchboard Operators

At his place of work the switchboard operator must perceive color information, namely white signal lamps for incoming calls, red end-of-call lights, and green operational control lamps. The observation distance is approximately 40 cm, the diameter of the lights is 8 mm. They are thus seen under an optic angle of approximately 1,16°. Under these circumstances even a color deficient person can not overlook the signal. Therefore switchboard operators may be deuteranomalous or protanomalous without jeopardizing the operational safety and task performance.

2. Teletype Operators

Teletype operators are not required to differentiate between colors in the line of duty. Color deficient subjects may enter this speciality without limitations.

3. Morse Code Operators and R/T Operators

No special demands are placed on the color vision of this personnel. On some devices red or green control lights must be perceived which give information as to the operational state of the equipment. There is no danger that these signal lights will be overlooked or not recognized by color deficient operators. Color deficient subjects may also enter these two career fields. While the tasks of the operators do not place any essential demands on color vision, the situation is somewhat different in the case of maintenance personnel of the Signal- and Telecommunications Corps.

4. Telephone Technicians and Telephone Construction Technicians

It may be said of soldiers in this speciality that high demands are placed on their color vision. Telephone lines, which are buried as so-called underground cables have up to 300 twin wires; mounting cables for a telephone trunk distribution and relay bays have up to 50 twin wires. These paired wires can be differentiated by the colors of their two wires. Thus, one wire of a twin wire may be red, the other one white, or one blue and the other one white. The remaining pairs may be yellow/white, green/white, brown/white and black/white. Then the next group of paired wires starts again with the colors red/white and so on. In a buried cable comprising 300 paired wires there is a multitude of confusing color impressions. Even higher requirements are placed on color vision when considering the color markings of paired wires in so-called switchboard cables. Here, the insulation material of one wire of paired wires is always red, and the marking of the other wire consists of blue, yellow, green, brown or black rings, approximate width 1,5 mm, which are laid on the white insulation material at spacings of 1 to 2 cm. In case of telephone interferences such cables must be "untied" in the relay bays in order to find and trace the defective paired wires. For this purpose the color marking is the only information available for the telephone- and telephone construction technician. Since repairs of this nature have to be performed predominantly under inadequate lighting conditions, color deficient subjects may commit gross mistakes. Particularly among the color rings of the paired wires of switchboard cables mix-ups between dark-blue, green and brown are almost inevitable.
Telephone- and telephone construction technicians must therefore have a complete color vision capacity.
Contrary to these careers, color markings are not of such great importance in the following special fields:

5. Teletype and Morse Code Technicians

Teletype- and radio sets also contain the red, green or yellow cables, approximately 1,5 mm thick, and sometimes also of brown or black color. The circuitry and arrangement of these cables is, however, relatively simple. If one considers that repairwork on this equipment is mostly performed under good illumination at the place of work, a confusion of these cables due to color deficiency is nearly impossible. Therefore these jobs may also be performed by deuteranomalous or protanomalous persons.

B. RADAR CONTROL SERVICES

This speciality comprises essentially the following groups:

1. Radar Aircraft Warning Service

2. Radar Forward Air Controllers
3. Radar Anti-A/C Rocket Control Service

Persons holding a Radar Air Status License, a Radar Operation License, Air Defense License or even an Air Defense Control License, originate from one of the above mentioned specialities. They are essentially responsible for supervisory and control functions and they observe the radar screens only in exceptional cases and then only for a short period of time.

Concerning these activities it can generally be said that neither observation, evaluation and image interpretation nor operation of the radar equipment require an absolutely normal color vision. What is required is a good differentiation between light intensities. Red or green control lights inform only about the functional state of the equipment and during reduced room illumination their intensity and brightness is sufficient and, having a diameter of 8 mm, they can be viewed under a sufficiently large visual angle (1,16°) from an observation distance of 40 cm. The control-sticks and buttons of radar equipment are in color on some models, which is completely uncalled for when handling them under mesopic visual conditions or even in complete darkness, but in such cases they have various shapes which are very appropriate and thus they can be differentiated through the tactile sense; the color is therefore not the only source of information. The same applies to careers of

C. MILITARY AIR TRAFFIC CONTROL

1. Radar-Approach Control
2. Radar-Ground Control Approach as well as to

D. ELECTRONICS WARFARE

1. Electronic Reconaissance

Another career within the speciality of electronics warfare, the

2. Communications Intelligence Operator

has hardly any visual tasks and consequently his color vision is not stressed. The maintenance and repair of equipment used in the Radar Control Service, in Military Air Traffic Control and in Electronics Warfare is the responsibility of technicians which in part are highly specialized in their activities. All of them are not only dealing with colored cables during maintenance and repair work, but also with colored condensators and above all with the color coding of small and minute resistors. Particularly the differentiation of micro resistors is taxiing the color sense of the technicians even more. The size of the resistors is as small as 3,7 mm in length and 1,7 mm in circumference. It is understandable, that these small dimensions prohibit marking by numbers or letters and the ring-like color coding indicates the value of resistance depending on the color, (two figures in addition to multiplication factor and tolerance value). When viewing these little resistors one believes on first sight that technicians having to handle them must in any case have a completely intact color vision. Critical analysis of every task process and work situation, however, leads to a different conclusion.

1. Search for the source of disturbance is done with the aid of a connection diagram and the ohmmeter. Both procedures involve no color vision.

2. In case of disturbances in an operational equipment not only single resistors are replaced but complete construction elements (Pies).

3. Defective construction elements (Pies) may only be repaired in the workshop; this means a good work place illumination and work without time pressure and without compulsive body posture. Under these circumstances a mix-up of smallest color codings is nearly impossible, even on part of color deficient technicians, which fact is supported by the author, who himself is deuteranomalous.

4. If difficulties should arise when differentiating between defective resistors (damaged color coding through thermal effects!) the resistance value may be found through measurement.

It may be said also in this case that deuteranomalous and protanomalous individuals may be accepted without risk in the above mentioned careers and especially if they have an appropriate professional background from their civil life. As an additional safeguard against erroneous handling color deficient technicians should predominantly be used for work in repair shops and optimal working conditions should be created for the recognition of color codings.

When studying reports in ophthalmological literature telling about errors of color deficient individuals in the selection of resistors in assembly plants of the electronic industries (3), one must keep in mind, that the work involved is not repair but purely production, and it is self-explanatory that requirements on color vision for those laborers with a view towards the work process are by far higher.
We must also be critical when assessing the demands on color vision for tower controllers. So far a completely normal color recognition was demanded from this group of persons. If one observes the work process of a tower controller, it becomes evident that color codings play a definitely secondary role. The following should serve as illustration:

1. Colored runway lighting.
2. Red lights to indicate obstacles on buildings of a certain height in the vicinity of an airbase.
3. Colored illumination of the sight of the light gun.

4. Colored markings on signal ammunition.
5. Red and white diagonal strips or checkered marks on obstacles and vehicles in the vicinity of or directly within the flightline area.
6. Perception of red transmitter control lights and of green control lights for incoming calls on the R/T installation of the tower.

Ref.1: The colored runway lighting is compulsory and follows a fixed pattern. The controller knows the location of the separate colored light rows, making an error even on part of color deficient individuals practically impossible. In order to monitor and make sure that all lights are illuminated the tower controllers have recently been equipped with runway light monitoring panels.

Ref. 2: The control of the red obstruction lights and markings is performed from the tower by means of binoculars. Determining whether these lights are illuminated or not is exclusively a factor of brightness perception and not of color perception.

Ref. 3: In exceptional cases, for instance when R/T communication fails, the controller must give red or green light signals with the so-called light gun to aircraft in the air or to those taxiing. To make sure which color filter has been placed into the light gun the controller checks the color of the front sight which he perceives when aiming the light gun under a visual angle of about 2,6 angular minutes and the position of the adjustment lever. Therefore errors on the basis of false color information are excluded. If you keep in mind that the smallest visual angle under which an abnormal trichromate can still recognize red and green surfaces as such is 105 angular seconds the color surface of the light gun sight subtending about 2,6 angular minutes is more than sufficient. The light gun, by the way, is only used very seldom. In 1969 H.L.GIBBENS and M.F.LEWIS (2) reported, that during 1 906 487 monitored flights in a certain area of the United States the light gun as a signal was only used in 0,062% of the cases. This is a percentage which causes us to reflect on the necessity of requiring tower personnel to have a completely normal color vision.

Ref. 4: Signal ammunition is marked by a relatively broad ring of the cartridge case in matching color and by a certain pattern of notches. Moreover the color coding is not the only source of information in such cases. Red, green and yellow signal lights must not be overlooked nor misinterpreted as to their color by the controller if they are fired from the tower, from some spot on the flight-line, or from an aircraft in the vicinity of the airbase, since red signals fired from VERY pistols have a hue of 656 nm and a brightness of 5.000 candelae and green signal ammunition has a hue of 540 and a brightness of 1.500 candelae, and they burn for five to seven seconds. It can be assumed that these color signals can be correctly interpreted even under IMC by deuteranomalous or protanomalous controllers.

Ref. 5: The red-white checkered pattern identifying obstacles next to the runway or vehicles permitted to drive near or on the runway will not be overlooked by a color deficient controller because these markings stand out more through their brightness contrast than through their colors.

Ref. 6: Red transmitting and green incoming call control lights on the R/T-Panel having a diameter of 8 mm are seen from an average observation distance of 40 cm under a visual angle of about 1,16°. The predominant number of anomalous trichromates perceives red and green light signals of 1° without fail on a color testing lantern after BEYNE. Moreover the color signal in this case too is not the only source of information. It assumes only a supporting role in addition to hearing and the tactile sense. Under these circumstances there are no high demands on the color vision of tower personnel. Therefore deuteranomalous and protanomalous subjects will hardly pose a threat to flying safety.

It is a frequently held opinion that technical personnel responsible for the maintenance of aircraft must have a fully normal color vision. This includes

1. Aircraft Mechanics
2. Engine Mechanics
3. Aircraft Electricians
4. Aircraft Electronics Personnel
5. Instrument Mechanics

Ref. 1: Even a color deficient aircraft mechanic will not overlook red, yellow, or green control lights on the panel, the red safety pin markers on the firing mechanism of the ejection seat and the red streamers of the safety pins on the landing gear or on the tail unit, since they again appear under a relatively large visual angle as seen by the observer. It can be difficult for a deuteranomalous and protanomalous aircraft mechanic to decide whether a liquid dripping from the fuselage is aircraft fuel or the red color hydraulic fluid. Smelling and feeling the liquid may help in such cases.

Ref. 2: The engine mechanic is also not required to perceive or differentiate between colors of vital importance. Fuel-, Pressure- and Hydraulic lines are marked in color, but besides this color a black-white symbol has been added (cross-checkered or diamond-shaped pattern) which facilitates discrimination of the lines mentioned without precise color perceptions.

Ref. 3: The same applies to an aircraft electrician. His activity in first echelon maintenance is confined to functional controls. At the present time, the majority of the electrical cables in the aircraft are marked white with black inscriptions. Red, blue, yellow and metal-colored terminals present themselves under a sufficiently large visual angle and it is safe to assume that deuteranomalous and protanomalous individuals can differentiate safely between them.

Ref. 4: In first echelon the electrician essentially performs function tests on electronic equipment. Sometimes he must replace entire construction elements. The perception of small color codings on the resistors, as for instance during repairwork on radar equipment, does not play any part in this activity.

Ref. 5: The instrument mechanic does not rely on color codings when checking the functioning of instruments. Reading aids on instrument displays in form of white, green, red and yellow sections have only a supporting function. He receives the information concerning the functional condition of the instrument indication by means of the pointer or scale position.

Disregarding flying personnel, an analysis of the conditions prevailing at the workplace of the most important other careers in the Air Force reveals, that perception and discrimination of color markings is indispensible and important for the safe performance of the task in only a few cases.

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APPENDIX

A. Signal and Telecommunications.

Specialities	Type of Color Display	Only Source of Information ? Yes	No	Auxiliary Markings or Cues?	Normal Color Vision Mandatory?
Switchboard Operator	Red, green & white control lights	–	X	Hearing cues	No
Teletype Operator	No color display	N/A	N/A	–	No
Morse Code Operator & RT / Operator	Red & green control lights	–	X	–	No
Telephone Technician & Telephone Construction Technician	Color markings of cables & twin wires	X	–	–	Yes
Teletype & Morse Code Technician	Red, green & yellow cables	–	X	Simple arrangement Connection diagram	No

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B. Radar Control Service.

Specialities	Type of Color Display	Only Source of Information? Yes	No	Auxiliary Markings or Cues?	Normal Color Vision Mandatory?
Radar Aircraft Warning Service	Red & green control lights Plotting boards	–	X	Fixed pattern	No
Radar Forward Air Controller	Red & green control lights Plotting boards	–	X	Fixed pattern	No
Radar Anti A/C Rocket Control Service	Red & green control lights Plotting boards	–	X	Fixed pattern	No
Radar Air Status License	Red & green control lights Plotting boards	–	X	Fixed pattern	No
Radar Operation License	Red & green control lights Plotting boards	–	X	Fixed pattern	No
Air Defense License	Red & green control lights Plotting boards	–	X	Fixed pattern	No
Air Defense Control License	Red & green control lights Plotting boards	–	X	Fixed pattern	No

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C. Military Air Traffic Control and D. Electronic Warfare.

Specialities	Type of Color Display	Only Source of Information? Yes	No	Auxiliary Markings or Cues?	Normal Color Vision Mandatory?
Radar Approach Control	Red & green control lights	–	X	Position of control sticks	No
Radar-Ground Control Approach	Red & green control lights	–	X	Position of control sticks	No
Tower Controller	Colored runway lighting Red lights on obstacles Light gun Color markings on signal ammunition Red & green control lights	–	X	Fixed pattern Brightness perception Position of adjustment levers Pattern of noches Position of control sticks	No
Communication Intelligence Operator	No color vision task	N/A	N/A	–	No
Radar Technician	Color cables Color coding of small resistors	–	X	Connection diagram Ohmmeter	No

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E. Aircraft Maintenance Personnel.

Specialities	Type of Color Display	Only Source of Information? Yes	No	Auxiliary Markings or Cues?	Normal Color Vision Mandatory?
Aircraft Mechanics	Red, green, yellow control lights Red markings on fuselage Red streamers Red colored hydrolic oil		X	Fixed pattern Fixed pattern Fixed pattern Smell & touch	No
Engine Mechanics	Color markings of fuel lines Color markings of pneumatic lines Color markings of lubrication lines Color markings of hydrolic lines		X	Markings by symbols	No
Aircraft Electricians	Color cables		X	Fixed pattern Clear arrangement Connection diagram	No
Aircraft Electronic Personnel	Color cables Color coding of small resistors		X	Replacement of complete elements only Ohmmeter Connection diagram	No
Instrument Mechanics	Red, green, yellow markings on the periphery of dials		X	Needle positions	No

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DISCUSSION

CHEVALERAUD

Je voudrais poser une question au Colonel Kürschner concernant la tolérance de certains dyschromates c ..ne les lecteurs d'écrans radar. Je pense que les contrôleurs d'écrans radar comme de radars de bord montrent une fatigue psycho-visuelle important quant à la détection des échos. On a pu vérifier que la fatigue visuelle est plus importante chez les gens porteurs d'anomalie du sens chromatique que chez les sujets qui ne portent pas d'anomalie du sens chromatique. Je voudrais demander si nous n'avons pas augmenté les risques d'erreurs, les risques des erreurs non perçues ou les risques des échos mal interpetés en acceptant dans cette profession des sujets dyschromatiques?

KURSCHNER

It is well known that visual fatigue in radar scope observers has many causes. The first place is surely occupied by disturbances of eye muscle functions, of accommodation, and refractive errors. If colour deficiences in these operators cause visual fatigue at all, which in my opinion has not been proved beyond doubt so far, this would only apply to protanope individuals. Since the shortening of the long wave end of the spectrum is a characteristic feature of this colour disturbance it may be safe to assume an impairment of the ability to differentiate between various brightness perceptions. Whether this fact will have a negative influence on the evaluation of the "blips" on the radar scope is subject to speculation and whether this is so in the case of protanomalous subjects is more than doubtful. This consideration does not apply to deuteranomalous and deuteranope subjects whose brightness discrimination ability is known to be good. We do not know of a case of a colour deficient radar scope observer in whom visual fatigue could definitely be traced to colour deficiency. In addition I should like to point out that the observations reported in my paper relate only to colour anomalies and not to colour blindness.

L'EXAMEN DU SENS CHROMATIQUE DANS LES FORCES AERIENNES FRANCAISES

par

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Malgré le développement des procédés électroniques dans la navigation aérienne, le sens chromatique des pilotes et des navigateurs reste fréquemment sollicité au cours des différentes phases du vol, notamment par :

- les voyants lumineux des tableaux de bord dont la tonalité est différente suivant qu'ils indiquent le bon fonctionnement, l'alerte ou l'alarme ;
- les feux de position et les feux anti-collision ;
- les feux d'approche et de balisage des terrains.

Lors des opérations de guerre, les décollages et les atterrissages dépendent aussi, sur certains terrains, d'une signalisation colorée (feux et fusées rouges et verts des "starters", dropping-zone). Qui plus est, la reconnaissance de cette signalisation colorée extérieure à l'avion est souvent rendue difficile par les conditions atmosphériques (brumes et brouillard, absence de contraste) qui créent un effet Bezold-Brucke. Elle est aussi très délicate lorsque la vitesse des avions est élevée (vol à grande vitesse et basse altitude).

La nécessité d'un sens chromatique différencié s'impose donc toujours dans la sélection et le maintien de l'aptitude au vol du Personnel Navigant, notamment dans les forces aériennes. Cet impératif s'explique aussi par la fréquence particulière des dyschromatopsies.

Les différentes statistiques démontrent que les atteintes héréditaires du sens coloré ont une fréquence voisine de 8 % dans la population masculine (Médecin en Chef RIU : 7,43 % ; 7,07 % parmi les recrues de l'Armée Belge). Il faut y ajouter les dyschromatopsies acquises (environ 0,5 %) qui sont parfois les seuls stigmates des altérations de la choriorétine ou du faisceau maculaire.

Les dyschromatopsies héréditaires varient dans leur intensité et leur fréquence relative comme le montre le tableau suivant (tableau n° 1).

Absence de toute perception colorée	Achromatopsie (1 cas sur 300.000 individus)		
	ROUGE	VERT	BLEU
Absence de la perception d'une fondamentale .... (25 %)	Protanopie ou ano. Dalton (10 %)	Deutéranopie ou ano. Nagel (14 %)	Tritanopie (1 %)
Déficience d'une fondamentale .... (70 %)	Protanomalie ou Ano. Hart (10 %)	Deutéranomalie ou ano. Rayleigh (59 %)	Tritanomalie (1 %)
Sensibilité chromatique atténuée .... (5 %)	"low discrimination" selon FARNSWORTH		
Sens coloré normal			

Sur le plan pratique nous retiendrons de cette classification :

- la gravité des confusions que peuvent réaliser un dyschromate de type Dalton et Nagel. Le premier peut méconnaître un feu rouge (qui lui paraît éteint) et le second peut le confondre avec un feu blanc.

Ces erreurs sont manifestes dans la signalisation colorée aéronautique comme l'ont montré les expérimentations de RUFF et SCHMIDT (tableau n° 2).

Proportion d'erreurs commises par des sujets atteints d'anomalie du sens chromatique dans la reconnaissance des signaux colorés

Anomalie	Feux de position fixes	Feux à occultation intermittente	Fusées
Anomalie Dalton	72 % d'erreurs	13,8 % d'erreurs	77,5 % d'erreurs
Anomalie Nagel	28,4 % d'erreurs		45,7 % d'erreurs
Anomalie Rayleigh	17 % d'erreurs		21,6 % d'erreurs

- le danger des anomalies "Rayleigh" et "Hart", qui s'explique par le fait que les sujets qui en sont atteints méconnaissent fréquemmont leur déficience chromatique. Ils peuvent en effet reconnaître parfaitement une plage colorée lorsqu'elle se présente sous une ouverture angulaire assez grande et que la durée d'exposition est suffisante. Par contre, lorsque la plage a une surface plus réduite et que le temps de présentation diminue, ces trichromates anormaux commettent des confusions dangereuses :

  - le "vert" peut-être vu "blanc"
  - le "rouge" peut-être reconnu comme un "orangé"

Ici aussi les erreurs dans l'appréciation des signaux colorés peuvent-être lourdes de conséquences, mais elles sont moins fréquentes que pour les dichromates (tableau n° 2). En fait, les dichromates de type Dalton ou Nagel paraissent impropres à reconnaître la signalisation colorée tandis que les trichromates anormaux peuvent, lorsque leur déficience n'est pas trop prononcée, être capables d'assumer des fonctions de sécurité en vol. Les tritanopes et les tritanomaux (erreurs pour le bleu) ne sont partiellement handicapés que pour la perception des feux de roulement au sol.

Les dyschromatopsies acquises sont de type rouge-vert (atteinte de la voie optique) et d'axe bleu-jaune (atteinte de la choriorétine maculaire). Les erreurs qu'elles entraînent sont pratiquement superposables à celles que commettent les dyschromates héréditaires de même type.

La sélection chromatique dans les Forces Aériennes Françaises intervient systématiquement lors des visites d'aptitude au Personnel Navigant (mais aussi au Personnel non Navigant chargé de la sécurité aérienne en vol). Elle doit dépister toutes les anomalies héréditaires ou acquises. Mais elle s'exerce aussi, lors des examens révisionnels, chaque fois que la moindre altération ophtalmoscopique de la choriorétine et du faisceau maculaire font suspecter une dyschromatopsie acquise.

La réglementation est en vigueur depuis 15 ans et permet de préconiser la valeur du standard S.C.A. (standard d'aptitude chromatique) qui s'intègre dans le profil global d'aptitude à côté du S.G.A. (aptitude physique générale), S.A.A. (facultés auditives) et S.V.A. (autres fonctions visuelles).

Ce standard ne tient pas compte de la détermination de la variété de dyschromatopsie mais essentiellement de la capacité chromatique pratique. En effet l'expertise recherche tout d'abord si la vision des couleurs est excellente (S.C.A./1). Lorsqu'elle ne paraît pas telle, on détermine si la capacité chromatique, quoique amoindrie, est encore suffisante pour assurer la sécurité en vol (S.C.A./2). Dans le cas contraire, le standard S.C.A./0 est attribué. Dans la pratique l'examen comporte l'utilisation successive des tables pseudo-isochromatiques d'ISHIHARA et de la lanterne chromoptométrique de BEYNE.

Le S.C.A./1 implique que le candidat ne commette aucune erreur ou hésitation caractérisée à la lecture des planches de la table d'ISHIHARA, faite à une distance de 7 5 cm, le test étant incliné à 45° sur l'horizontale et éclairé à l'aide d'une lampe de type Easel Mac-Beth. Chaque planche est présentée pendant deux secondes.

Le S.C.A./2 est compatible avec l'identification des lumières de couleur utilisées en aéronautique. Aussi, les sujets commettant des erreurs à la table d'ISHIHARA, sont examinés à l'aide de la lanterne chromoptométrique de BEYNE, présentant la lumière transmise par des écrans colorés, correspondant aux feux : rouge, jaune, vert, bleu et blanc (dont la longueur d'onde dominante correspond réellement à celle des feux et balises de l'aéronautique).
La distance d'examen est de 5 mètres (diamètre apparent de deux minutes) et le temps de présentation est de 1/25ème de seconde. Les feux présentés un à un, à différentes reprises doivent-être chaque fois dénommés exactement sans hésitation pour que le S.C.A./2 soit attribué.

Le S.C.A./0 est immédiatement appliqué dès qu'une erreur ou une hésitation est constatée.

Cette technique d'examen comporte certains avantages :

- rapidité de l'expertise dont la durée n'excède pas cinq minutes ;
- sélectivité qui répond aux impératifs d'une sélection pratique ;
- efficacité qui peut toutefois être discutée pour le test d'ISHIHARA, qui en principe ne "répond" pas devant les anomalies d'axe tritan acquises ou héréditaires. Toutefois l'expérience montre que les sujets qui en sont atteints hésitent à la lecture des tables où existent des tonalités bleues, ce qui incite à les examiner à la lanterne de BEYNE où leur déficience, si elle est prononcée, apparaît nettement à la dénomination du feu coloré de couleur bleue.

Dans les cas douteux, l'Expert peut d'ailleurs faire appel aux autres procédés classiques de l'examen du sens chromatique (anomaloscope de Nagel, tests de FARNSWORTH) qui, permettant d'apprécier qualitativement et quantitativement le degré de l'anomalie, étayent ainsi sa décision d'aptitude ou d'inaptitude.

Les résultats que nous avons obtenus dans la pratique de cette expertise portent sur 44.193 candidats examinés pendant 10 ans pour l'aptitude au vol.

a) le S.C.A./1 (excellente vision des couleurs) a été reconnu chez 99,20 % des sujets. Cette forte proportion s'explique par le fait que les candidats avaient été le plus souvent présélectionnés lors de leur scolarité ou de leur engagement dans l'Armée de l'Air, avant de s'orienter vers le Personnel Navigant.

b) le S.C.A./2 a été attribué dans 0,4 % des cas.

c) le S.C.A./0 a intéressé 0,4 % des candidats.

Lors des examens révisionnels, les dyschromatopsies acquises ont entraîné une inaptitude définitive dans moins de un cas sur 1000 (S.C.A./0).

La sécurité de ces modalités d'expertise apparaît à l'étude des dossiers d'accidents aériens car aucun d'entre eux n'a pû être imputé à une défaillance du sens chromatique.

En conclusion, les conditions d'expertise du Personnel Navigant permettent l'attribution rapide et sûre d'un standard d'aptitude chromatique (S.C.A.) qui intervient dans l'établissement des profils à l'emploi dans les différentes spécialités (par exemple S.C.A./1 pour un pilote de chasse, S.C.A./2 pour un mécanicien).

L'inaptitude définitive à toute fonction aéronautique de sécurité est ainsi déterminée par un procédé pratique, qui met le candidat dans les conditions de visibilité des feux colorés utilisés dans l'aéronautique.

Le rôle de l'Expert n'est pas seulement négatif, car il collabore avec les Ingénieurs de l'aéronautique pour adapter les procédés de signalisation et d'information aux possibilités chromatiques des Navigants.

DISCUSSION

WHITESIDE Je voudrais poser une question sur le tableau numéro 2 que vous aviez montré. J'ai partiellement compris, que parmi les anomalies de Dalton vous aviez 73% de fautes commises avec des feux fixes tandis qu'il n'y en avait que 13,9% avec des feux occultants. Voudriez-vous expliquer cela, s'il vous plait?

PERDRIEL Oui, je pense que c'est vrai: nous avons observé que des feux d'occultation intermittents ont la propriété de solliciter la rétine d'une manière, si on peut dire, saccadée et de ce fait entre chaque occultation il existe un contraste, et ce contraste aide à la perception du feu coloré. Tandis que lorsqu'il existe un feu fixe, il se produit un phénomène d'adaptation progressive à la vision colorée, et en particulier des auteurs allemands ont bien montré l'importance de ce phénomène d'adaptation, et c'est pour cette raison que le feu d'occultation intermittent est plus intéressant. D'autant plus, je pense qu'il y a un élément psycho-sensoriel: le phénomène de stimulation successive entraîne, si l'on peut dire une augmentation de l'activité de la substance réticulée et, par là même, une perception, et non plus une sensation, qui est beaucoup plus approfondie pour la détermination de la couleur. Je pense que l'on peut expliquer cette discordance qui est effectivement réelle et que nous avons d'ailleurs retrouvée; c'est l'intérêt de ces feux d'occultation car, même chez les dyschromates, ils sont mieux perçus, de telle sorte que chez un sujet normal, cette perception serait encore plus favorisée par le système d'occultation.

BANDE Vos résultats ne semblent-ils pas indiquer que la présélection (scolaire et autre) est trop négative et brise des vocations avant même qu'elles aient pu être examinées par nos bons soins?

PERDRIEL Cette présélection est indépendante de notre volonté, mais je crois qu'elle est utile, car elle évite d'orienter vers la carrière aéronautique des adolescents qui ont une insuffisance notoire du sens chromatique. Dans les cas douteux d'ailleurs, nos Confrères Ophtalmologistes civils nous adressent ces futurs candidats et nous les examinons à titre officieux pour connaître leur capacité chromatique pratique.

KURSCHNER My first question is: When examining with the chromoptometric lantern according to Beyne you limit the size of the test object to 2^{o} and the perception time to 1/25 s. Test instructions issued in 1962 for this lantern demand a minimum test target size of 1^{o} ; why are you now testing with 2^{o} ? Is not a perception time of 1/25 s somewhat unrealistic? Which colour signal is seen for such a short time under operational conditions?

My second question is: Am I correct in understanding that you will admit colour deficient applicants to a flying career as pilots if they pass the test with the chromoptometric lantern during initial examination?

My third question is: According to our experience a considerable number of deuteranomalous individuals will only confuse white with green and vice versa when examined with the chromoptometric lantern, and then only with a target size of 1^{o} and a perception time of 1/5 to 1/10 s. Do you believe that these errors still constitute a risk to flying safety under present day conditions? Ingeborg Schmidt, whose work you have quoted, has already answered in the negative in 1942.

PERDRIEL Il est exact que les premières instructions d'utilisation de la lanterne de Beyne précisaient que l'ouverture angulaire de la plage lumineuse colorée devait être de 1 degré. Par la suite un rectificatif a étendu cette ouverture à 2 degrés. Cette modification est liée au fait que nous nous sommes rendus compte que les sujets absolument normaux ne voyaient pas le feu bleu sous une ouverture de 1 mn, et qu'ils le distinguaient fort bien sous l'ouverture de 2 mn. Ceci n'a rien d'étonnant, car on sait que les cônes du bouquet central de la fovéola sont physiologiquement aveugles au bleu. Le temps de perception de 1/25ème de seconde peut paraître effectivement très bref, mais il faut penser que le pilote ne peut disposer que d'un temps très court pour apercevoir la fin de l'éclairement d'une fusée ou d'un feu intermittent.

Les candidats élèves-pilotes "Chasse et Transport" doivent posséder une excellente vision chromatique lors de leur visite d'admission, ce qui implique la reconnaissance des feux colorés de la lanterne de Beyne.

Je rappelle que nous n'utilisons pas l'ouverture angulaire de 1 degré avec la lanterne de Beyne, et que, de ce fait, nous n'avons pas la notion d'erreurs particulières de ces deuteranomales à la lanterne de Beyne utilisée sous cette ouverture (nous réalisons toujours une ouverture de 2 degrés).

Je pense toutefois que l'ouverture de 1 degré est très sévère et que dans tels cas, s'il n'y a pas d'erreurs à l'ouverture de 2 degrés, les sujets peuvent être admis dans le Personnel Navigant.

HISTORY, RATIONALE, AND VERIFICATION OF COLOR VISION STANDARDS AND TESTING IN THE UNITED STATES AIR FORCE

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SUMMARY

The flyer utilizes largely form vision; however, color vision is a bonus that increases his efficiency without demanding much further conscious effort. As long as there is a surplus of candidates in the manpower pool, the color vision problem then remains largely academic. One would simply test for physiologic perfection; however, when the surplus of candidates no longer exists or to better utilize those with special talents, then a relaxation of the color requirements is in order. This paper will review the color vision testing and selection procedures utilized in World War I and World War II by the US Army Air Corps. One of the major projects of the Ophthalmology Department at the School of Aviation Medicine (SAM) at Randolph Air Force Base, Texas during World War II was research on color vision. The color vision tests recommended as a result of this work are still the tests of choice in the US Air Force. The color vision standards for flying in the US Air Force have recently been changed for the first time since World War II. Mild defectives scoring 50 or better on the SAM color threshold tester (CTT) are now accepted into flying training. A ten-year retrospective study of 4801 experienced flying personnel provides strong evidence that these standards are valid. The handling of color vision defective cases referred to the USAF School of Aerospace Medicine (USAFSAM), Brooks Air Force Base, Texas, is also outlined.

INTRODUCTION AND HISTORY

"The proper recognition of color plays an important part in the success of all types of fliers. On the maps generally used by observers the woods are green, rivers blue, roads yellow, railroads black, and towns brown. Sky-rockets with a parachute are white, red, and green, and cartridges, with and without parachutes, are of similar colors. Bengal flares which are used in woods and heavy underbrush are red and white. The aerodromes use red and green, or white lights for homecoming planes, while the planes themselves carry a red light on the port and a green light on the starboard side. In a "dog fight," fliers of great experience state that it is necessary to recognize colors on a machine to avoid the possibility of shooting down a friend. All types of fliers (over land) are liable to have to select quickly a place for a forced landing. In this connection, Captain S. J. Allen, Royal Air Force, states that good color vision is necessary to detect differences of color on the ground. "A light field indicated stubble; a dark field, grass or wet and marshy ground; dark green stripes running across fields, water or ditches; yellow, sand; and rough brown spots, bumps." If a flier who has been successful in training is found later to be color blind, he can be used as an instructor, ferry pilot, or night bomber, provided only white lights are used at his aerodrome. In great emergencies he could be used as a day bomber owing to the height at which he usually flies."[1] This paragraph was taken from Aviation Medicine in the A.E.F., from the chapter "The Eye in Aviation," written in 1919 by Colonel W. H. Wilmer and Major Conrad Berens. It contains much that is still important in flying aircraft today.

With the advent of larger, faster, higher flying, instrument-navigated aerospace craft, the role of color vision should decrease in importance; however, flying under operational conditions, such as in Southeast Asia, the pilot once again has returned to the situation as noted in the opening paragraph. During World War I the medical examiners felt that color vision testing was an important part of the physical examination of applicants for the Aviation Section of the Signal Corps. Testing for color deficiencies was done by the Jennings' self-recording color test.[1] A perforated cardboard exhibiting confusion colors was placed before the applicant. A shade of red or green was placed before him and he was asked to select, by punching through the perforations, anything in the chart that contained red or green. Punctures were permanently recorded on a blank beneath the chart. The instructions on the back of the blank, 609A.G.O. (Physical Examination Form), also stated that if a Jennings' test was not available, the medical officer should select a skein of any shade of red or green worsted and have the candidate select in separate piles all skeins containing red or green. Further, if confusion was still present, color lights at 20 ft. should be used as a test before rejecting the candidate.[2] It is evident that even at the very onset there were color vision testing problems.

During the period between World War I and World War II the Department of Ophthalmology at the School of Aviation Medicine had carried out a series of tests for the detection of color blindness. Experimentation was carried on with Holmgren skeins, Jennings' self-recording, Stillings' pseudo-isochromatic and Williams' lantern tests. A recommendation was made in 1935 that the Ishihara test be adopted.[3]

When the Ishihara test was first included in the examination, those who failed were rejected, but by 1940 several other tests, such as the Stillings' pseudo-isochromatic plates, spectroscopic, Holmgren yarn matching, and lantern tests were also used to examine the extent of color blindness.[4] The authorized

tests for central color vision in 1941 were the Ishihara test or the Stillings' pseudo-isochromatic plates and Holmgren skein of yarn. Sufficient data had been accumulated to warrant recommendation that the Holmgren test, expressed in terms of the Edridge green classification, be discontinued. A study of 50 individuals who made errors on the Ishihara test indicated that about 3/4 of these could not be qualified or disqualified on the results of the Holmgren yarn test used as a "confirmatory test." Eighty percent of the entire group also made significant errors on the Williams' lantern test.[5]

During World War II a large number of studies on color vision were made at the Army Air Force School of Aviation Medicine, at Randolph Field. Most of these were accomplished under the direction of Louise L. Sloan, Ph.D. At the time these studies were initiated, in 1942, four tests of color vision were authorized for use by the US Army Air Force. There were two basic tests and two adjunct tests. The basic tests were the Ishihara (8th edition) and the American Optical Company (AOC) pseudo-isochromatic plates; the two adjunct tests were the Holmgren wool test and the School of Aviation Medicine lantern test. Ability to pass these last two tests was used to qualify men as "color safe" under certain conditions. Regulations were rather vague as when to apply these tests; consequently, it was left to the individual examiner to select the testing device and method of scoring so as to distinguish between those who did and those who did not meet this criterion. Studies to determine the most practical tests for color vision were carried out in a most logical and efficient manner. First, a job analysis to determine the type of color discrimination required of aircrew personnel was done. Following this, most of the tests that were available at that time were investigated. In certain of these tests modifications were made, and, in addition, certain new tests were developed for use by the US Army Air Force. A list of the tests investigated between 1942 and 1945 follows: American Optical Company pseudo-isochromatic plates, Rabkin polychromatic plates, School of Aviation Medicine anomaloscope, the Rand anomaloscope (Bausch and Lomb), Inter-Society Color Console (ISCC) single judgment test, Eastman hue discrimination test, Farnsworth-Munsell 100 Hue test, terrain test, and Peckman vision test. There were also tests made on a number of lanterns: Canadian Lantern and the SAM CTT, or Color Threshold Test. The sum total of all these investigations was that in 1943 the American Optical Company abridged set of pseudo-isochromatic plates was selected as the most suitable basic test. This abridged version was composed of 17 test and 2 demonstration charts. Of the numerous quantitative tests investigated, the SAM Color Threshold Test was rated to be the most satisfactory for the classification of flying personnel.[6] These tests continued when the USAF became a separate service. However, further investigations culminated in the assembling of the current American Optical Company 15 Plate Test (14 test plates and 1 demonstration plate) in 1951. This set was adopted by the US Air Force in 1953 as the official color vision screening test.

Dvorine color plates at first were printed in two volumes, in 1944, under the title "Dvorine Color Perception Testing and Training Charts." A second edition of these plates was published, in 1953, under the title "Dvorine Pseudo-Isochromatic Plates." These also had 14 diagnostic plates and 1 demonstration plate. The American Medical Association approved this edition in 1954, and approval was given in 1959 by the Medical Material Coordination Committee for the use of this edition by the Armed Forces of the United States.[7]

From 1959 through 1970 there were two basic screening color vision tests: that is, the American Optical Company and the Dvorine 15 Plate tests. These were considered to be interchangeable. These tests were not identified separately in the Federal Stock Catalogue and, therefore, when requested through supply channels, one might receive one or the other. These tests were utilized for screening of Classes I and IA candidates. AFM 160-1 (Medical Examination and Medical Standards) listed in paragraph 69 under Color Vision: Flying Classes I and IA - Causes for Rejection: Five or more incorrect responses. Flying Classes II and III could pass the color vision standards if an individual made a score of 50 or better on the VTA Color Threshold Tester (grade 1); however, applicants for the designation of flight medical officers and flight surgeons must pass the color vision test plates (VTS-CV).[8] These standards remained in force until 1 July 1971. The present AFM 160-1 (C1) now lists, in paragraph 4-12, Color Vision: Flying Classes I, IA, II, and III - Causes for Rejection: Five or more incorrect responses in reading the 14 test charts of the Standard Color Vision Test set (VTS-CV), unless examinee makes a score of 50 or better on the color threshold tester (VTA-CTT).[9] As of this date, then, the US Air Force is following the example of the US Navy of allowing the mildly color defectives to enter into flying training. Table I summarizes color vision testing from 1918 to 1971. A number of authors have brought out the point that inadequacies and unknown factors in the testing procedures have allowed numerous color defectives to enter training undetected. The final sentence of Sloan's 1946 publication is pertinent to the next part of this paper. The sentence reads: "Studies are also needed to provide further information as to the degree of defect in color vision compatible with the various duties of Air Force personnel."

TABLE I

Color Vision Tests Used by US Army Air Corps and the US Air Force

Date	Tests
1918	Jennings' Self-Recording Color Test
1935	Ishihara Pseudo-Isochromatic Plates
1941	Ishihara or Stillings' Pseudo-Isochromatic Plates
1942	Ishihara - American Optical Company (AOC) Pseudo-Isochromatic Plates
1943	AOC Pseudo-Isochromatic Plate Test (17 test plates, 2 demonstration plates) (SAM Color Threshold Test (CTT) quantitative test developed)
1953	AOC Pseudo-Isochromatic Plate Test (14 test plates, 1 demonstration plate)
1959	Dvorine Pseudo-Isochromatic Plates (14 test plates, 1 demonstration plate)
1959-1970	AOC and Dvorine for Classes I & IA - SAM CTT for Classes II & III, except flight medical officer and flight surgeon (same as Classes I & IA)
1971	AOC and Dvorine Plates or SAM CTT (50) for Classes I, IA, II and III

RETROSPECTIVE STUDY OF COLOR DEFECTIVE FLYING PERSONNEL SEEN IN THE OPHTHALMOLOGY BRANCH, USAFSAM, JANUARY 1960 TO NOVEMBER 1971

From January 1960 to September 1971 all personnel referred for clinical evaluation were screened for color vision defects using a set of Dvorine plates (VTS-CV). These included 4447 experienced pilots and navigators and 354 additional experienced flying personnel who were not pilots or navigators. See Table II. Only 40 color defectives were seen during the ten and one-half year period. Of these 40, only 9 had been referred for evaluation of their color vision. Eight of these 9 were student pilots with less than 60 hours of flying experience. Five of the 40 had ocular diseases, including 3 with central serous retinopathy, one with macular degeneration, and one with retrobulbar neuritis. Another was referred for a contact lens for irregular astigmatism following corneal surgery. The remaining 25 were picked up on routine screening here at the USAF School of Aerospace Medicine (USAFSAM) with the VTS-CV plates and were originally referred for nonocular diagnoses. The most common referral diagnoses are listed in Table III.

TABLE II

Total Flying Personnel Screened at USAFSAM with VTS-CV

From January 1960 to September 1971

Pilots	3509
Navigators	938
Total	4447
Other Flying Personnel	354

Total Flying Personnel Screened at USAFSAM with VTS-CV

From September 1966 to September 1971

Pilots	1492
Navigators	364
Total	1856

TABLE III

Reasons for Referral to the USAF School of Aerospace Medicine

DIAGNOSIS	NUMBER OF PATIENTS
Color vision abnormality	9
Special duty examinations (ARPS, etc.)	6
ECG abnormality	4
Central serous retinopathy	3
Syncope, loss of consciousness	3
Diabetes mellitus	3
Psychiatric	2
Retrobulbar neuritis	1
Macular degeneration	1
Other nonocular diagnoses	8
Total	40

From January 1960 to April 1964 the only tests routinely used at USAFSAM for evaluation of color vision deficiencies were a Nagel anomaloscope (Schmidt-Haensch #585) and the VTS-CV test plates. Quantitative results on the anomaloscope, including midpoints of ranges of acceptability on the Rayleigh equation, have not been recorded. In January 1965 the VTA-CTT lantern was added, and since January 1968 the Farnsworth 100 Hue Test and the Farnsworth Dichotomous Test (Panel D-15) have also been used frequently.

Twenty-seven of the total of 40 color defectives seen had congenital defects. Five were acquired, and 6 were not determined. Two were reported to have very minimal deuteranomalous defects on the Nagel anomaloscope but could pass the VTS-CV given here. These two cases are not included in Tables IV and VI. The five cases of acquired defects will not be given in detail here. None were grounded due to their mild losses of color discrimination, but 2 had associated visual acuity and visual field losses which were judged hazardous.

The remainder of this report will be limited to considerations of the 27 who were definitely diagnosed as having congenital color vision defects. Twenty of these were deuteranomalous, 2 were deuteranopes, 2 had protanomaly, 1 was a protanope, and 1 was apparently tetartanomalous. See Table IV. First, a brief description of the very few defectives seen at USAFSAM who had considerable experience in various flying careers will be given. This is followed by an attempt to determine the significance of the marked relative paucity of various types of color defectives among 4447 experienced pilots and navigators. Finally, a similar examination will be made of the color defectives among flying personnel who are not pilots or navigators.

TABLE IV

Types of Congenital Color Vision Defects among Various Career Fields

Seen January 1960 to September 1971

Career Field	Deuteranomaly	Protanomaly	Deuteranopia	Protanopia	Type of Defect and Whether Congenital or Acquired Undetermined
Pilots	12*	0	1≠	0	2
Navigators	1	0	0	0	1
Other Flying Personnel	2	2	0	0	1
Non-flying	0	1	0	0	2
Student Pilots	5	1	1	1	0

(One apparent tetartan is not listed.)

*Eight of these were seen prior to September 1966 and are not included in Table VI.

≠This single deuteranope was also seen prior to September 1966 and is not included in Table VI.

A Few Successful Defectives

Among those failing the VTS-CV plates here with congenital defects were 12 with considerable flying experience. All denied ever having any difficulty in performing their jobs due to defective color vision. None of these experienced men were grounded due to the discovery of their defects. See Table V. Eight were pilots with an average of 3274 hours apiece and a total of 26,196 hours for the eight. The other 4 included a navigator (1900 hours), a flight engineer (8500 hours), a boom operator (7000 hours), and a flight surgeon (8000 hours). Eight of the 12 had CTT scores of 40 or above (grade 1 defect), and the 6 of these who were pilots seem to substantiate the recent policy change allowing candidates for pilot training to fail the VTS-CV if they can achieve a score of at least 50 on the VTA-CTT. Two pilots and the flight surgeon made grade 2 scores (35-49) on the VTA-CTT and one flight engineer and one pilot (a Major General) made grade 3 scores (below 35). These successful pilots with low CTT scores are not inconsistent with Sloan's conclusions from her work on the CTT. She pointed out that a score of 50 on the CTT would "not qualify men unable to discriminate red, green, and yellow biscut gun signals but would disqualify some who are able to do so."[6]

Also, Steen and Lewis in a recent study for the FAA Civil Aeromedical Institute found that about one third of color defectives with scores below 50 on the CTT could identify 5-second biscuit gun signals from 1500 feet away at night.[10]

Eleven of the 12 experienced flying personnel in Table V had a deutan type of defect; the only protan was a flight surgeon. Of the 4 other protan color defectives seen at USAFSAM since 1960, none have been experienced pilots or navigators. One protanomal and one protanope were eliminated from pilot training. Two other protanomals were a flight steward and a personnel director who was being reconsidered for reassignment to missile duty. The complete absence of protanomalous pilots and navigators is probably significant, and will be considered in detail in a subsequent section.

TABLE V

Experienced Flying Personnel with Color Vision Defects

Case Number and Rank		Position	Hours	Color Vision Defect	No. of Plates Failed on VTS-CV	VTA-CTT Score	Grade of Defect
4	Capt	Pilot	2800	Deuteranomaly	More than 4	55	1
5	Capt	Pilot	1696	Deuteranomaly	More than 4	59	1
7	Col	Pilot	3200	Deuteranomaly	More than 4	60	1
13	1st Lt	Pilot	500	Deuteranomaly	14	61	1
22	1st Lt	Pilot	2300	Deuteranomaly	5	64	1
31	Maj	Navigator	1900	Deuteranomaly	13	62	1
38	MSgt	Boom Operator	7000	Deuteranomaly	14	51	1
10	Maj	Pilot	4200	Deuteranopia	14	35	2
25	Maj	Pilot	5500	Deuteranomaly	11	48	2
26	Col	Flight Surgeon	8000	Protanomaly	More than 4	39	2
20	Maj Gen	Pilot	6000	Deuteranomaly	12	29	3
35	MSgt	Flight Engineer	8500	Deuteranomaly	12	33	3

Whether these very few successful pilots and navigators are sufficient to indicate that their type of defective color vision is not really a handicap may in part be determined by a statistical consideration of how many color vision defectives should have been seen at USAFSAM if defective color vision is compatible with success as a pilot or navigator versus how many were actually observed. This analysis can begin by estimating the proportion of defectives who probably passed undetected into pilot training, or the misclassification rate.

Misclassification rates

All but one of the 8 student pilots listed in Table IV had been accurately classified as defective on the initial pre-training examinations. The single exception, a protanope, had memorized the order of plates and later had sufficient difficulty with signal lights at night on landing that he decided to return to the flight surgeon's office for further testing. Among the 19 nonstudents definitely diagnosed as having congenital defects however, 10 had an innacurate "VTS-CV passes" or "passed - on record" on their previous physical examinations. This 52% error rate is similar to that found by Paulson[11] at the US Naval Marine Medical Center. Only about 60% of the color defectives sent to her laboratory between 1955 and 1965 had been correctly identified. Farnsworth lantern results were reported only 71% accurate. Previous records of CTT scores were available here for only 8 men. Three of these 8 were sufficiently at variance with scores obtained here that previous improper technique could be suspected. The percentage of color defectives seen at USAFSAM with incorrect records has no direct correlation to the percentage of color defectives who have been allowed to slip through the screening examinations and into pilot and navigator training. The fact that a substantial percentage of the defectives seen here did have inaccurate records does indicate in a general way that the field testing and recording during the years that the experienced pilots and navigators in this study were undergoing their pre-training examinations were less than completely adequate.

This inadequacy cannot be attributed to the test used for initial screening. Several investigators have found the VTS-CV to be very efficient in separating color normals from defectives when administered properly. A committee of Farnsworth, Sloan, and Judd[12] found that the Armed Forces Color Vision Test series of plates (AOC) would detect about 99% of defectives under ideal conditions. Seefelt[7] similarly found only 1.9% of defectives misclassified by the AOC plates and 4.9% misclassified by the Dvorine version of the VTS-CV plates. (His misclassification rates for normals were 9.3% for the AOC and 0.0% for the Dvorine.) Claro[13] found that the Dvorine version of the VTS-CV misclassified 4% of defectives, and AOC misclassified 6% of defectives. (Claro's misclassification rates of normals were 4% for the Dvorine and 3% for the AOC.) Crawford,[14] Sloan,[15] and Belcher[16] also found similar results with the Dvorine plates.

The VTS-CV in both major forms appears to be reasonably adequate; the faults must therefore lie in improper procedures commonly used in testing and recording in the field. How commonly the VTS-CV is improperly administered or inaccurately recorded cannot be known precisely at present. In 1944, Sloan[17] reported that only about 3% of Aviation Cadets were being rejected for color vision deficiency instead of an expected 6% to 8%. Even if a few who would have been applicants for pilot training eliminated

themselves because of prior knowledge of their defects, this error rate in detection would still approximate 50%. Sloan attributed this to the use of only a few poorly selected charts instead of the complete test, and previous coaching of applicants. Paulson[11] gave questionnaires to 83 hospital corpsmen attending the School of Submarine Medicine, and 83% of them were willing to state that they had routinely given the USN color vision tests (plates and Farnsworth lantern) using improper technique. Only 50% of the testing facilities at which these corpsmen served had the required daylight lamp. Farnsworth[18] has estimated that if the plates are given under ordinary incandescent light, about half the deutans will pass undetected.

Even when the procedure used for the plates is incorrect, they are still susceptible to previous familiarization by the examinee. Sloan[19] tested 7 men who had been given the older, unabridged series of the AOC charts during every day of a course of red and green light treatments given to "cure" their color blindness. She found that these men did indeed do fairly well on the plates they were familiar with, even though the other tests still indicated deficient color perception. Also, the order of the plates can be memorized if it is not changed periodically.

Considering the various ways in which the VTS-CV can be improperly administered and inaccurately recorded, Paulson's disturbing questionnaires answered by hospital corpsmen, and Sloan's estimate of a 50% error rate in detection of color defectives in the field, it appears reasonable and probably conservative to estimate that during those years that the experienced pilots and navigators in this study underwent their pre-training examinations, about 25% of color defectives passed undetected into flying training.

Chi-square analysis

If the estimate that 25% of color defectives passed undetected into flying training is accepted for the experienced pilots and navigators of this study, then a useful comparison can be made between the expected number of color defectives and the actual number observed from January 1960 to September 1971. All patients seen at USAFSAM were screened with the VTS-CV, Dvorine, administered using the proper technique and frequent changes in plate order. The VTS-CV could be expected to detect virtually all those with protanomaly, protanopia, deuteranomaly, and deuteranopia, as shown in the previous section. In an unselected Caucasian male population the incidences of these defects are as follows: protanomaly, 1.0%; protanopia, 1.2%; deuteranomaly, 4.6%; and deuteranopia, 1.4%.[20] The total of these percentages is 8.2%. Twenty-five percent of 8.2% is 2.05%. The total number of experienced pilots and navigators seen over the past ten and one-half years is 4447. (See Table II.) The number of color defectives expected to have been seen at USAFSAM is 2.05% X 4447, or 91. Only 17 color defectives were seen among the experienced pilots and navigators. The difference between 91 and 17 for this large sample is highly significant by Chi-square analysis ($p < 005$). This is evidence that at least some varieties of defective color vision are incompatible with success as a pilot or navigator.

The precision of this analysis could be improved if the proportional distribution of the different types of color vision defectives among those passing undetected into flying training were known. Then, some insight could be gained as to which types of color vision defects are greater handicaps in flying and which may be less hazardous. Though this distribution cannot be known precisely, there is a good reason to believe that the proportion of each type of defect among the defectives who passed undetected into flying training was quite similar to that of the defectives in an unscreened population. This is simply the frequent observation that when the VTS-CV is improperly administered, it is administered so improperly that the effect is the same as administering no test at all.

Paulson[11] questioned those color defectives whose previous medical records were inaccurate in order to determine what errors were being made. It was found that very few of the defectives misclassified were "borderline" cases. In most instances the tests had been administered so improperly in the field that the effect was the same as not administering the color vision test. Often the examinees were allowed to watch other candidates taking the test and were able to memorize correct responses; one examinee even reported that he passed the test by having a tall normal who was in line behind him whisper the correct responses. Also, examinees very frequently reported that a passing score had been entered in the record even though they failed the test.

The 10 seen at USAFSAM with inaccurate VTS-CV scores on previous physical examinations could not be interviewed in this retrospective study as to how they managed to "pass" the VTS-CV on previous examinations. Sufficient information to gain insight into this problem was available for only three deuteranomals, one protanomal, and one protanope. Only two of the deuteranomals appeared to be true "borderline" cases who could pass the plates on some occasions and not on others, depending on the lighting used and which edition or brand of plates was presented. One deuteranomal and the protanope admitted to memorizing the plate order at the facilities where they had been tested previously. The protanomal admitted that though his record indicated "VTS-CV passed" he had never been given the test. One additional case seen too late to be included in the statistics for this study, a mildly deuteranomalous pilot, admitted to owning a set of the plates and studying them extensively prior to each physical examination for the first five years of his career. Although more data on this point would be desirable, our experience does appear to parallel that of Paulson; frequently the color vision tests have been administered so improperly that the effect was the same as administering no test at all.

Incandescent or other improper lighting used with the VTS-CV may favor deuteranomals, but due to the high frequency of grossly improper testing and recording, substantial numbers of protanomals, protanopes, and deuteranopes undoubtedly slipped through the screening examinations in the field, at least until recently. Because protanopes are more often aware of their defect prior to initial physical examinations, they can be expected more often to anticipate difficulty with the VTS-CV and to devise ways of getting around this obstacle. It appears probable, therefore, that the distribution of types of color vision defects among the previously estimated 25% of defectives undetected on pre-training examinations would be reasonably similar to the distribution of types found in a similar male Caucasion population before screening.

No re-test data of the flying personnel in this study performed just after finishing their pre-training examinations are available to verify this conclusion. Re-test data on a set of current student pilots would not be relevant because color vision screening tests are presently more standardized than they were when many of the flying personnel in this study and in Paulson's study took their pre-training examinations.

If it is accepted that at least 25% of color vision defectives passed undetected into flying training and that the distribution of the different types of defectives approximates that seen among the defectives of an unscreened population, then the numbers of each type expected to be seen later in their careers at USAFSAM may be calculated and used in a Chi-square analysis. Unfortunately, the color vision defects of three of the pilots and navigators seen between January 1960 and August 1966 were not precisely categorized as to type of defect. Complete data on pilots and navigators are available only for the period from September 1966 to September 1971. Only this five-year data were used in Table VI. During these five years 1856 pilots and navigators were seen at USAFSAM. (See Table II.)

TABLE VI

Numbers of Different Types of Congenital

Color Vision Defects Expected and Observed Among

Pilots and Navigators Seen from September 1966 to September 1971

(N=1856)

	Expected*	Observed	Significance of Difference (Chi-square method)
Protanomals	5	0	$p < .025$
Protanopes	6	0	$p < .025$
Deuteranomals	21	4	$p < .005$
Deuteranopes	6	0	$p. < .025$

*Expected column calculated with the assumption that 25% of defectives of each type were not detected in pre-training examinations.

Each figure in the "expected" column of Table VI was calculated by multiplying the incidence of the type of color vision defect in an unscreened population by 25% and then taking this as a percentage of 1856. For protanomaly this was 0.01 X 0.25 X 1856, or 5. Except for 8 deuteranomalous pilots and one additional pilot with deuteranopia who were seen prior to September 1966, the "observed" column corresponds to the figures listed in Table IV. The values of p listed in Table VI appear to indicate that at least some degrees of severity of all four of the common types of color vision defects are significant handicaps to becoming and/or remaining a successful pilot or navigator.

The absence of protanopia and protanomaly

The complete absence of any protanopes and protanomals among the 4447 experienced pilots and navigators seen at USAFSAM between January 1960 and September 1971 may be more than merely coincidental. Protanopes and protanomals usually total about 2.2% of an unscreened Caucasian male population.[20] Even if only 10% of protans had passed undetected into flying training, the difference between the expected 0.1 X 0.222 X 4447, or 10, and the observed zero would still be significant ($p < .005$).

Cameron,[21] working at the Swiss Air Force Institute of Aviation Medicine, found the protanomalous candidates did so poorly on the K.B.B.-Martin lantern that he decided to reject all candidates with any degree of protan deficiency. (The K.B.B.-Martin lantern is similar to the CTT except that it has only four colored signals--red, green, orange, and white.) Similarly, Laxar[22] found that protans identified fewer of the full set of Ishihara plates (11th ed.), made more errors on the Farnsworth Dichotomous (Panel D-15) Test, and identified fewer of the Hardy-Rand-Rittler plates than deutans.

Claro[13] reported that 100% of a group of 10 protans failed the CTT (score below 50), but only 60% of 40 deutans failed. CTT scores of 18 deuteranomals seen here ranged from 29 to 64 and averaged 53. Twenty-eight percent had scores above 50. CTT scores of 4 protanomals ranged from 21 to 46 and averaged 37. (This difference in means was not significant, possibly due to the small number of protanomals.) Two deuteranopes had CTT scores of 35 and 34; one protanope had a score of 42.

Both of the laboratory tests cited here and the practical tests of professional flying appear to select heavily against the protan.

Evidence that the CTT score is approximately correct

Although there were no protan defectives among the 4447 experienced pilots and navigators, 13 deuteranomals were seen. Of these 13, 10 had a sufficiently mild defect to score above 50 on the CTT. The other three had scores of 29, 35, and 48. Large population data concerning the percentage of deuteranomals who usually fail the CTT is not available. Claro,[13] however, found that 65% of a "deutan"

population of 38 composed of both deuteranomals and deuteranopes made less than 50 on the CTT. If it is assumed that the ratio of deuteranomals to deuteranopes in his group was the usual 4.6 to 1.4 and that all deuteranopes failed the CTT, then he had about 29 deuteranomals, of whom 55% failed and 45% passed the CTT.

Suppose for a moment we assume that the CTT failing score is essentially valid and that all deuteranomals who pass undetected through the screening examinations and who would not have made a passing CTT score would not be seen at SAM because they would not succeed as pilots or navigators. Similarly, those who pass through the field examinations undetected who would have made a passing score on the CTT would be successful and would be seen later at USAFSAM. The incidence of deuteranomals in an unscreened population is 4.6%. If only 25% passed undetected into training, then 4.6% X 25% X 4447, or 51, deuteranomals should have been seen during the ten-year period. Using Claro's data and the assumptions mentioned above, about 55%, or 28, could be expected to fail the CTT. Only 3 pilot and navigator deuteranomals who failed the CTT were recorded during the ten years. Unfortunately, three color defectives seen prior to September 1966 were not categorized as to type of defect. Even if all three of those uncategorized had been deuteranomals who would have failed the CTT, the difference between the expected 28 and the observed 6 would still be significant ($p < .005$). This indicates that deuteranomaly severe enough to produce a score below 50 on the CTT is not compatible with success as a pilot or navigator.

Using similar logic, it would be expected that 4.6% X 25% X 4447, or 23 pilot and navigator deuteranomals passing the CTT would be seen. Only ten were recorded. Because of the three uncategorized color defects, it is possible that 10, 11, 12 or 13 deuteranomals who could pass the CTT were in fact seen during the ten-year period. Whichever of these figures is correct, the difference between the expected 23 and the number of deuteranomals seen who could pass the CTT is significant ($p < .05$ or smaller). This would indicate that at least some deuteranomals who can achieve a score over 50 on the CTT still may not do well as pilots or navigators.

A score of 53, as mentioned by Sloan[23] in her first report of the performance of normals on the CTT, may be more appropriate. It should be remembered, however, that the estimate that 45% of deuteranomals would pass the CTT is central to the statistical considerations given in this section, and that this estimate was based on data from a small and incompletely described group of "deutans" given by Claro.[13]

TABLE VII

Number of Different Types of Congenital

Color Vision Defects Expected and Observed Among

Other Flying Personnel (not Pilots or Navigators) Seen

from January 1960 to September 1971

(N=354)

	Expected*	Observed	Significance of Difference
Protanomals	1	2	Not significant
Protanopes	1	0	Not significant
Deuteranomals	4	2	Not significant
Deuteranopes	1	0	Not significant

*Expected column calculated with the assumption that 25% of defectives of each type were not detected in pre-training examinations.

Color vision defects among other flying personnel

The numbers of each type of color vision defective observed from January 1960 to September 1971 among flying personnel who were not pilots or navigators is given in Table VII. The sample size (354) is considerably smaller than those available for pilots and navigators, and one defective was not categorized. The figures in the "expected" column were calculated with the same 25% assumption used for Table VI. None of the differences were significant. Whichever type of defect the undetermined case had is unknown, but adding it to any of the figures in the "observed" column of Table VII does not make any of the differences significant. This tends to suggest but does not conclusively demonstrate that flying personnel who are not pilots or navigators do not require the same degree of color discrimination to be successful in their professions.

Statistical implications summarized

We have made the conservative assumption that at least 25% of each type of color defective passed undetected into flying training during those years when 1856 currently experienced pilots and navigators were undergoing pre-training examinations, and then asked the question: "Which types of color defectives pass through flying training and succeed in their career fields long enough to be seen eventually at USAFSAM?" This approach appears to be more valid than any biscuit gun or flare test devised. This analysis combined with examinations of 2591 additional pilots and navigators has led to the conclusion

that protanopia, deuteranopia, any degree of protanomaly, and all but the mildest degree of deuteranomaly are almost never compatible with a successful career as a pilot or navigator. How mild a deuteranomaly can be allowed in these fields has yet to be established, but those making well above 50 on the CTT who had not memorized its sequence of colors are probably safe. A similar examination of 354 flying personnel who were not navigators or pilots suggests that these other flying personnel do not require the same degree of color discrimination to be successful in their professions.

CONCLUSION

Color vision defects are almost exclusively an affliction of males. If only color normals are accepted as flyers, 8 to 10% of the male population would be excluded. Color vision tests and refinement of these procedures, as shown, can identify approximately 3% of the color defectives who are considered to be safe to fly. Beyond this it is not very practical to expend much more effort to squeeze out the last one half of one percent of these color defectives. It has been the opinion of many concerned with color vision testing that the 6% classified as moderate and severe color defectives are a hazard in the flying environment. The retrospective study reported here shows that a score of 50 or better on the VTA Color Threshold Tester appears to be compatible with a safe flying career. The present combination of VTS-CV and the VTA-CTT is more than adequate to screen and quantify mild defectives if the tests are administered properly. Better instruction given to the flight surgeons, aeromedical technicians, and the newly emerging field of ophthalmic technicians (912X0) should help improve the administration of these color vision tests.

A survey of the literature shows that color vision researchers constantly strive to identify and qualify "safe" flyers. Our concern as military flight surgeons should go beyond this, since we should be selecting the "best" of these flyers. "Safe" ones at times may not just be good enough. For 20 years there has been talk of engineering color requirements out of flying.[24] This has not come to be and probably will not. This is so because flying is becoming much more complex and demanding on human physiology and perception.

Color vision is a good cue that can be used advantageously by equipment designers. It allows more information to be gathered and stored in the "computer" at very little cost in time and thought. Should we give up such an important advantage? If military aircraft are becoming larger, more expensive, faster, and fewer in number, why should we select their few captains with physiologic deficits of any kind? Perhaps the most practical solution to the problem will be to select classes of flyers to be equated against types of aircraft and kinds of mission.

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COLOUR VISION IN THE CANADIAN ARMED FORCES

by

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Prior to the unification of the Canadian Armed Forces in 1968 the Royal Canadian Navy, the Canadian Army and the Royal Canadian Air Force each had their own requirements, medical standards and methods of evaluation of these standards. These medical standards included that of colour vision. The Navy considered it important having four classifications dependent on the ability to pass the Ishihara Standards Book Test and the Green Edwards Lantern Test. The RCAF had three classifications, Colour Vision Normal, Colour Defective Safe and Colour Defective Unsafe. The first based on passing the A.O. Isochromatic Book Test without error, the second passing a colour lantern test and the third achieved by failing both tests.

The Army ignored colour vision totally - their regulation reading "The recruit will not be tested for colour vision" Assuming the Army had its expected 8% ratio of colour defectives in its recruits, it is interesting to note that despite this neglect of colour vision as an employment factor in assignment to trade or corps there was no apparent operational or functional deficit reported in army operations. One assumes that those were unable to perform some specific function properly were assigned to others they could perform.

The Air Force had definite colour vision requirements, aircrew requiring normal colour vision for pilot candidates but only colour defective safe levels from experienced pilots and other aircrew. Three trades, Fighter Control Operator, Aircraft Control Operator and Laboratory Assistant had a requirement for normal colour vision, whilst the rest required colour defective safe levels. The RCN had four standards based on passing the Ishihara Colour Plates and the Green Edwards Lantern - normal colour vision being requirement for all executive officers and certain upper deck ratings. but in general the requirements paralleled those of the RCAF.

Unification in 1968 brought a revamping of the existing trade structures within the three services and there were created 97 general trades and 29 officer classifications.

Faced with the unenviable task of correlating physical abilities to employment, the medical branches of the Canadian Forces - now called the Canadian Forces Medical Services - relied in respect to colour vision. on experience and a pragmatic sense rather than embarking on what would necessarily have been series of individual studies in each trade or classification.

Consultations were held with civilian advisors, with trade instructors and managers, with experienced officers in various fields, and the conclusion was that normal colour vision was no longer a requirement in any of the new trades or officer classifications including those of pilot and executive naval officers. The colour vision requirement for each trade or classification is appended (Appendix A) The method of colour vision testing utilised previously in the RCAF was retained as the testing method. It, as previously indicated, utilised the A.O. Isochromatic Plates and the RCAF Colour Lantern Test. Appendix B lists the technique of testing.

Dependent on test results a person is now classified as

CV1 - Pass the Colour Plate Test

CV2 - Pass the Colour Lantern Test

CV3 - Failed the Colour Lantern Test

One may ask what has happened to those soldiers whose previous experience was in the Army and whose trade requirement now included a CV2 category if testing revealed them to be in fact colour defective level 3? It would be patently unfair to restrict their careers because of a clinical test and in these cases waivers of non restriction were added to their documents if in the opinion of their superiors their colour defect had not proved any barrier to their on-job performance.

Though we have assiduously asked for reports of incidents which are felt to be colour vision related in all trades and classifications, none have been forthcoming and we can only presume, in the absence of these reports that the system adopted is adequate for our needs.

APPENDIX A

MINIMUM COLOUR VISION STANDARDS
FOR THE
INITIAL ASSIGNMENT TO TRADES

TRADE	COLOUR VISION
ARMOUR	3
ARTILLERY	2
INFANTRY	3
FIELD ENGINEERING	3
SIGNALS	2
SEA WEAPONS	2
FIRE CONTROL (SEA)	2
MARITIME AIR	2
AIR TRANSPORT	2
INTELLIGENCE	2
WEATHER	2
PHOTOGRAPHY	2
CARTOGRAPHY	2
TOPOGRAPHY	2
AIR TRAFFIC CONTROL	2
AIR DEFENCE CONTROL	3
BOATSWAIN	2
COMMUNICATIONS OPERATOR	2
COMMUNICATIONS MAINTENANCE	2
RADAR MAINTENANCE	2
ELECTRONIC (SEA)	2
RADIO (SEA)	2
SONAR (SEA)	2
RESEARCH	3
MARINE ENGINEERING	2
HULL ENGINEERING	2
ELECTRICAL ENGINEERING	2
DIVER	2
VEHICLE	2
LAND WEAPONS	2
ELECTRO MECHANICAL	2
AVIATION	2
AVIONICS	2
SAFETY SYSTEMS	3
INSTRUMENT ELECTRICAL	2
WORKSHOP	2
AIR WEAPONS	2
AIRCRAFT HANDLING	2
STRUCTURES	2
MECHANICAL	3
FIRE PREVENTION	3
LABORATORY TECHNICIAN	2
MEDICAL	3
DENTAL	3
SECURITY	2

TRADE	COLOUR VISION
CLERICAL	3
ACCOUNTING	3
PHYSICAL AND RECREATION	3
FOOD SERVICES	3
MUSIC	3
POSTAL	3
DRAUGHTING	2
SUPPLY	3
TRANSPORTATION	3
PARACHUTIST	3
SUBMARINER	2
CREWMAN	2

MINIMUM COLOUR VISION STANDARDS FOR THE INITIAL ASSIGNMENT OF OFFICERS

	COLOUR VISION
ARMOUR	3
ARTILLERY	3
INFANTRY	3
AIR NAVIGATOR	2
PILOT	2
AEROSPACE ENGINEER	2
COMMUNICATIONS/ELECTRONIC ENGR	3
LAND ORDNANCE ENGR	3
MARITIME ENGR	2
MILITARY ENGR	3
DENTAL	3
DENTAL ASSOCIATE	3
MEDICAL	3
MEDICAL ASSOCIATE	3
NURSING	3
CHAPLAIN(P)	3
CHAPLAIN (RC)	3
AIR TRAFFIC CONTROL	2
AIR WEAPONS CONTROL	2
FLIGHT ENGINEER	2
LEGAL	3
LOGISTICS	3
MARITIME SURFACE	2
MARITIME SUB MARINE	2
METEOROLOGY	3
MUSIC	3
PERSONNEL DEVELOPMENT	3
PERSONNEL SUPPORT	3
SECURITY	3
SUPPLY	3
ACCOUNTS	3
PERSONNEL	3
MEDICAL	3
MEDICAL ASSOCIATE OFFICERS	3
CHAPLAINS	3

APPENDIX B

INSTRUCTIONS FOR TESTING COLOUR VISION

GENERAL

1. Colour deficiency is a sex-linked hereditary defect which passes from affected father to unaffected daughter who in turn will have affected sons. About 8 percent of males and 0.8 per cent of females are colour deficient.

2. Candidates for service in the Canadian Forces will be tested by the Colour Plate Test using Pseudo-insochromatic Plate Set, RCAF modification(CFMS Cat.No.6516-21-116-3110). Those candidates who fail the Colour Plate Test will be tested by the Colour Perception Lantern Testing using the Colour Perception Lantern (CFMS Cat,No. 6515-21-804-7980)

3. Candidates who normally wear spectacles will have their colour vision tested while wearing their spectacles.

COLOUR PLATE TEST

4. This consists of a series of 25 plates on each of which is placed a test figure. The cards shall be kept in their box when not in use as they may fade if exposed to too much direct light. Excessive handling will soil them and reduce their efficiency.

5. On the back of each card will be found two numbers e.g., "3.27", the first is the number of the plate in the series and the second is the number which a candidate with normal colour perception will read. Of the 25 plates, those numbered 1 to 12, inclusive, must be read correctly. The remaining plates have been inserted merely to avoid any possibility of memorization.

6. All plates shall be viewed in the holder under a MacBeth Easel Lamp. A card is placed in the holder of the lamp and the candidate is asked to read the figure which he sees in it. This procedure is followed for all plates. Care should be taken that the candidate does not see the numbers on the back of the cards. Each candidate must read all 25 plates, after being allowed 5 seconds to recognize each plate. After each plate has been viewed it shall be laid on the table face up.

INTREPRETATION

7. The plates numbered 1 to 12 are the essential ones and these are divided as follows in two separate groups:

a. Group 1 includes plates number 1,4,5,6, and 11. Each of these plates must be read correctly. Any deviation is scored as an error.

b. Group 2 includes plates number 2,3,7,8,9,10 and 12. Slight errors are permitted here. That is, if the candidate sees, say, 38 instead of 56, on Plate No 7, and if he makes the same mistake when the same plate is presented again in a different sequence, then an error is not counted. However, if he does not see any number, or if he seen different numbers on subsequent presentations of the same plate, then an error is scored.

ASSESSMENT OF COLOUR PLATE TEST

8. If no error is scored against a candidate in the Colour Plate Test then he has passed this test and will be graded category CV1 - Colour vision normal. Those candidates who have an error scored against them have failed this test and will be given the Colour Perception Lantern Test.

COLOUR PERCEPTION LANTERN TEST

NOTE: The importance of carrying out accurately, and in detail the following instructions cannot be over emphasized. Medical officers shall not vary the technique from that which follows.

9. The candidate is seated in a darkened room, at a distance of 20 feet from and directly in line with, the lantern, which is set at eye level.

10. The colours the candidate is to be shown are the first to be "defined" by showing him the single aperture knob positions 1,2, and 3, saying "This is green, this red, and this white". He is also instructed thus, "You will be shown a series of coloured lights and as each one appears, you are to say whether it is red, green, or white. No other colours are used in this test."

11. The test is begun by setting the control knob at any one of the eleven positions possible other than 1,2,or3. Using a single aperture, the shutter is held open for as long as the candidate requires to arrive at a decision. As soon as his answer has been recorded, the shutter is closed. The control knob is then turned either clockwise or anti-clockwise to the next position and then the procedure is repeated. This is continued until one complete rotation has been made. The colour named shall be recorded accurately for each knob position.

12. Both apertures are now opened, and the subject is instructed: "During the second half of the test, you will be shown two lights at each time. Please name them always from your left to your right, again confining your answers to red, green, and white."

13. The operator then completes another rotation of the control knob, holding open the shutter for as long as the candidate requires at each position of the knob. Again each colour is recorded as named.

14. If at any time the candidate employs names of colours other than red, green, and white, he shall be told merely, "Please remember that the only colours used in this test are red, green, and white". No error is scored for answers such as yellow, orange, pink, blue, etc., provided that the correct answer is given after the above reminder.

15. If, at the end of two complete rotations of the filter control knob (two sequences consisting of 11 single lights and 11 pair), no errors are made, further testing is not required. If, on the other hand, one error is made, the whole test shall be repeated, beginning at a different starting point and rotating the control knob in the opposite direction to that used in the first test. The current test will be completed before the second is given.

16. When a mistake is made in the first test, it is essential that the complete test be repeated once.

ASSESSMENT OF COLOUR LANTERN TEST

17. Candidates shall be assessed as follows:

a. Pass. No errors on the first test, or one error on first test but none on repeat test.

b. Failure. Two or more errors on first test, or one error on first test and one or more on repeat test.

18. A candidate who fails the Colour Plate Test but who passes the Colour Perception Lantern Test will be graded CV2 - Colour Defective Safe (CDS)

19. A candidate who fails the Colour Plate Test and the Colour Perception Lantern Test will be graded CV3 - Colour Defective Unsafe (CDU)

RECORDING OF RESULTS

20. Form 2040, Colour Perception Lantern shall be completed in duplicate for each candidate tested on the Colour Perception Lantern. One copy shall be inserted in the candidate's medical documents and the second copy forwarded CFHQ Attn: Surgeon General for inclusion in the individuals CFHQ medical envelope.

21. Space has been provided in the column headed "Knob Position" in proforma in which to indicate the starting point and direction of each rotation. An arrow shall be placed in the appropriate column opposite the beginning of each sequence, the direction of the arrow to indicate the direction of rotation.

DISCUSSION

TREDICI — How did you arrive at the figure of 99.3%? From the testing that you are using, described in the paper, you cannot state these were normal because you did not test for complete normalcy within the class II category. There would be a lot of individuals who would not be completely normal because some, about 30%, would fail the test plates. Was that taken into consideration?

LIDDY — The figure of 99.3% refers to 99.3% of 1200 candidates who presented at the Institute of Aviation Medicine for final testing. They were pre-screened to a certain degree and only 7 of these candidates were colour defective; 5 of these were deuteranomalous and 2 were protanope.

KURSCHNER — What colour signals or colour markings are mandatory for Fighter Control Operators, Aircraft Control Operators and Laboratory Assistants?

LIDDY — This is the old classification for which I am not responsible. I think the requirements here were that Fighter Control Operators needed to have completely normal colour vision and laboratory assistants are presumed to need good colour vision because of the spectroscopic analysis required in various laboratory testing procedures. In the case of the third group, the aircraft control operators, I presume the standard was formulated in relation to movements of aircraft and vehicles on runways.

KURSCHNER — Under what visual angle are colour test lights submitted in the colour test lantern according to Green-Edwards?

LIDDY — The lantern has a distance of 1 inch between the apertures. The apertures are 1/50 of an inch. The distance of testing is 20 feet (6m).

Essai de Standardisation de la Catégorisation des Anomalies de la Vision des Couleurs en milieu militaire, ainsi que des Méthodes employées en vue de leur dépistage.

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1. Introduction.

Il nous semble indispensable, afin d'obtenir une sélection uniforme, de standardiser notre catégorisation et nos tests de la vision des couleurs, ainsi que en ce qui concerne les tests pigmentaires, leur éclairage.

Les tests employés devraient être bien précisés et leur nombre devrait être réduit. Ils permettront cependant une catégorisation à base scientifique, réflétant de façon raisonnable le degré de gravité théorique et pratique de l'anomalie.
La classification des individus en catégories, établies en fonction du nombre de réponses érronées à l'un ou l'autre test, en particulier aux Planches d'Ishihara, devrait être évitée ; ces catégories se sont en effet avérées être assez hétérogènes aussi bien en ce qui concerne la nature de l'anomalie que quant à sa gravité.

2. Tests Employés.

Pour établir un diagnostic d'anomalie de la vision des couleurs, il faut employer conjointement plusieurs tests : des épreuves pigmentaires (cartons pseudo-isochromatiques et épreuves d'assortiment) et l'anomaloscope, sans lequel la classification d'une dyschromatopsie congénitale reste un diagnostic de probabilité.

a. En vue du dépistage, les Atlas Pseudo-isochromatiques d'ISHIHARA, de HARDY, RAND and RITTLER et la TRITAN PLATE de FARNSWORTH devraient être obligatoirement employés. Le principe bien connu de ces cartons est que certains signes sont rendus invisibles, du fait que les couleurs des pastilles constituant le fond, forment avec les couleurs des pastilles constituant le signe, des paires de mêmes leucies et dont les lieux se situent sur la même ligne de confusion.
Selon que les différences entre les couleurs soient plus ou moins dissemblables, le carton servira à la détection ou à la classification. Les signes de certains cartons, dits de "contre-épreuve" ne seront par ailleurs pas reconnus par les sujets normaux : les différences entre les couleurs ne concernent que la composante bleue et masquent les composantes rouge et verte mal différenciées par les sujets protan et deutan. Ceux-ci lisent ainsi le signe normalement invisible, l'exagération éventuelle des contrastes y aidant également.

b. L'ATLAS d'ISHIHARA est trop connu pour que nous en donnions une description.

Sachons qu'il s'agit d'un bon test de détection protan-deutan, très ou même trop sensible. Il ne permet cependant que très imparfaitement de distinguer le type protan du deutan, du fait de la non-lecture fréquente des deux chiffres des planches conçues à cet effet. Il ne permet également pas de se faire une idée de la gravité théorique de la dyschromatopsie, et ignore la détection des déficiences tritan, voire tétartan.

c. L'AO-HRR ou ATLAS de HARDY, RAND et RITTLER, édité par l'American Optical Company, permet une bonne étude de la direction de l'axe neutre et une appréciation valable de la gravité théorique du féficit. Il nous aidera donc lors de la catégorisation que nous venons d'énoncer plus haut.

Il contient également des cartons visant les déficiences d'axe bleu-vert (tritan - tétartan). La présentation des planches d'arrière en avant facilitera son emploi et raccourcira ainsi le temps d'examen, tout en évitant l'utilisation des planches de démonstration.

d. La TRITAN PLATE de FARNSWORTH, planche unique conçue pour le dépistage de la tritanomalie et de la tritanopie, est très efficiente pour la détection des déficiences d'axe vert-rouge ou seul le carré vert est visible.Sa présentation ne demande quasi pas de temps et elle devrait donc être incluse dans la batterie des tests de routine.

e. Le PANEL D- 15 ou TEST DICHOTOMIQUE DE FARNSWORTH, épreuve bien connue d'assortiment, sera d'une grande utilité lors de la catégorisation, pour reconnaitre le type et apprécier la gravité de la déficience.

Les confusions se font entre des couleurs plus ou moins diamétralement opposées par rapport à un gris de même leucie.

L'ajoute des lignes de référence tétartan et scotopique, établies par Verriest en augmentera l'utilité.

Sachons que les sujets normaux effectuent parfois quelques permutations marginales, ou une seule confusion diamétrale de type tritan ou tétartan.

Ce test ne sera appliqué qu'aux dyschromates puisqu'il ne s'agit pas d'un test de détection. Le nombre et la direction des confusions diamétrales nous renseignent quant au type et à la gravité de la déficience.

f. Le 100-HUE de FARNSWORTH, autre épreuve d'assortiment répartit les pions en quatre plumiers de façon à ce que, contrairement au Panel D-15, les erreurs ne peuvent se faire de façon diamétrale, mais en fonction de la courbe des seuils différentiels chromatiques.

Le nombre et la gravité totale des erreurs sont estimés par chiffre-index total ou score.

La distribution des erreurs, des maximas se situant aux points de tangence des lignes de confusion, sera étudiée par voie graphique. Un artifice d'inscription permettra d'obtenir en cas de dyschromatopsie le plus souvent un tracé d'aspect bipolaire qui permettra de distinguer un axe passant par le centre des maximas, axe perpendiculaire à l'axe neutre, et caractéristique du type de la déficience.

Comme pour le panel D-15 Verriest y a ajouté une ligne de référence tétartan et scotopique.

Ce test ne peut certainement pas être retenu comme test de routine. Il est utile pour la classification et l'appréciation de la gravité.

Ses inconvénients sont sa médiocrité au point de vue détection, le long temps de passation, et la nécessité d'une bonne coopération.

g. L'ECLAIRAGE des tests pigmentaires devrait être obligatoirement fait à l'aide d'une source de lumière de distribution spectrale proche de l'étalon-C de la Commission Internationale de l'Eclairage, de 75 lux au moins.

La Macbeth Ade-10 à chevalet convient très bien pour les cartons pseudo-isochromatiques, tandis que la Macbeth BBX-324 ou BBX-320 est tres pratique pour l'exécution des épreuves d'assortiment et de classification d'échantillons colorés.

h. Seul l'ANOMALOSCOPE de NAGEL permettra finalement la transition d'un diagnostic de probabilité d'une dyschromatopsie congénitale, établie par les tests précités, au diagnostic de certitude et à la classification exacte.

L'exécution de cette épreuve d'égalisation en trois "volets" peut dans la majorité des cas être confiée à un technicien. Il recherchera si l'équation moyenne de Rayleigh est acceptée ou non, et si l'individu testé obtient ou non l'égalisation de la radiation jaune avec la radiation rouge et la radiation verte. Cet examen ne prend que très peu de temps puisque les périodes d'observation ne peuvent de toute façon pas excéder 10 secondes afin d'éviter les phénomènes d'adaptation locale.

Dans cette forme simplifiée, il peut donc faire partie de l'examen de routine. Au besoin, l'examen peut être complété par l'ophtalmologiste qui lui recherchera tous les lieux pour lesquels les deux moitiés du champ sont métamères.

h. Si les épreuves de dénomination ne permettent pas d'établir aisément le type et la gravité d'une déficience, nous pensons que, par exemple, la LANTERNE de BEYNE autoriserait certains "repêchages" ou latitudes dans l'application des critères d'aptitude dans quelques cas particuliers.

Ces dérogations restent à discuter.

3. Conclusions, Catégorisation.

Afin d'obtenir une sélection uniforme, nos tests de la vision des couleurs et leur éclairage éventuel devraient être standardisés.

En vue du dépistage, tous les candidats seraient soumis aux tests d'Ishihara, l'AO-HRR, la Farnsworth-Tritan Plate, et l'examen en trois "volets" à l'anomaloscope de Nagel.

Les tests pigmentaires seraient éclairés à l'aide d'une source de lumière de distribution spectrale proche de l'étalon-C de la C.I.E.

La gravité et le type d'une déficience seront appréciés à l'AO-HRR, au Panel-D-15 de Farnsworth, à l'anomaloscope de Nagel, et éventuellement au 100-Hue de Farnsworth. Plaideront pour un di-chromatisme, plutôt que pour un tri-chromatisme anormal : un AO-HRR "strong", un maximum de confusions diamétrales au Panel D-15 et l'existence d'une zone d'équation caractéristique à l'anomaloscope. Des résultats très déficients et du type scotopique au Panel D-15, au 100-Hue et à l'anomaloscope, feront admettre un mono-chromatisme.

L'individu testé devrait être catégorisé sous une des dénominations suivantes : normal, protanomal (léger, moyen, grave), deutéranomal (léger, moyen, grave), protanope, deutéranope, achromate typique, achromate atypique, et "autres déficits".

Cette dernière dénomination couvrirait entr'autres les déficiences tritan et tétartan, qui seraient obligatoirement mis en observation dans un service hospitalier disposant d'une installation électro-rétinographique, et permettant l'établissement d'un bilan fonctionnel poussé afin d'établir si elles sont acquises ou congénitales, ce qui parait de plus en plus être la toute grande exception.

Si l'individu déficient n'a subi qu'une partie des tests préconisés du fait que l'aptitude en jeu n'en valait pas la peine, l'expert pourra le plus souvent encore faire appel à cette catégorisation. Des symboles repris en marge, et indiquant les épreuves subies, permettront dans ce cas de juger à quel point le diagnostic en était un de probabilité, et s'il y a lieu ultérieurement de le compléter.

Il nous semble qu'à partir d'une telle catégorisation, des critères uniformes et des aptitudes nuancées pourraient être discutées, permettant éventuellement l'accès de certains dyschromates à des fonctions réservées jusqu'à présent aux seuls normaux.

L'on peut se demander enfin s'il ne serait pas indiqué d'établir tel que Verriest l'a fait en 1968 un ensemble organisé de tests : un ensemble constitué de certains cartons sélectionnés de l'Ishihara et de l'AO-HRR sur la base de l'appréciation analytique des efficiences, ainsi que par le Panel D-15 et l'Anomaloscope. La catégorisation et le diagnostic des différentes déficiences s'en trouveraient posés avec plus de facilité et avec plus de certitude.

DISCUSSION

PERDRIEL — Je voudrais féliciter Mr. van de Casteele de son étude très détaillée des tests actuellement utilisés pour la détection des anomalies du sens chromatique. Toutefois, je voudrais discuter certains points de sa communication:

1) Le test d'Ishihara nous a paru toujours supérieur au point de vue de la détection des anomalies au test de Hardy-Rand-Rittler.

2) Le test de Farnsworth 15 Hue nous paraît nettement insuffisant, sauf pour les dyschromatopsies acquises. Nous préférons de beaucoup le test de Farnsworth 100 Hue qui apporte une discrimination beaucoup plus efficace.

3) La lanterne de Beyne est à notre avis un appareillage excellent qui donne une notion réelle de la capacité chromatique de l'aviateur.

VAN DE CASTEELE — Je suis tout à fait d'accord et d'ailleurs je n'ai pas placé le panel de 15 parmi les tests de dépistage. En ce qui concerne le nombre des tests à appliquer, je suis tout à fait d'accord sur le fait que cela dépend un peu du temps dont on dispose et du nombre des candidats. C'est pourquoi j'ai dit que l'on peut adopter encore cette classification.

VOS — Do you really use all these tests? Do you have arguments why you consider these tests as relevant, whereas many other authors tend to denigrate most tests and turn to lantern-testing only? What are your comments on the fact that H-R-R test is not manufactured any more?

VAN DE CASTEELE — At the Air Force Medical Center and for the flying personnel the tests are used as indicated. This means that "normal subjects", of course, will not undergo the time consuming Panel D-15 or 100 Hue tests. For "general purposes" at the Selection Center of the Armed Forces only the AO-HRR, the Ishihara, and a lantern (designed and constructed by the Belgian Army and commercially not available) are used.

The aim was to obtain uniform testing conditions and uniform categorisation. If, for example, it was generally decided that a pilot needs to have "normal" color vision, a testing, as indicated, would select quite fairly such "normals", and re-tests later on would again confirm the initial examination. If, on the contrary, it was decided that certain colour-defectives might be allowed to fly in certain conditions, it seems to me that these individuals could be selected on the basis of the advocated categorisation. Numerous papers exist that appreciate the value of colour tests in the detection and assessment of the degree of gravity of colour vision defects. An excellent experimental one, for example, is VERRIEST, G.: "Appréciation analytique des efficiences de quelques tests pour le diagnostic des déficiences congénitales de la vision des couleurs." in Scritti in onore del Prof. Luigi Maggiore, 1968, Maccari editore, Parma. The address of the author is: Department of Ophthalmology, University Hospital, De Pintelaan, B-9000 GENT, Belgium.

I hope that the AO-HRR test will be manufactured again, as it is a valuable test when used in combination with other tests.

COLOUR VISION REQUIREMENTS IN DIFFERENT OPERATIONAL ROLES

by

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SUMMARY

A study into the importance of colour vision in the various operational roles of the Royal Air Force and Army Air Corps has been carried out. It is considered that good colour acuity, although playing a valuable part in the total process of visual perception, is not of paramount importance. It would be possible by altering the present chromaticities of red and green signal colours to admit for all aircrew duties, except those of Close Air Support, the more severe grades of red green defective. It is thought, however, that the small gain in recruiting would not warrant the resulting expense and disruption of present services.

The pseudo-isochromatic plates provide a simple and rapid method of detecting even minor anomalies of colour vision and should be retained as the initial examining procedure.

With present standards the lantern is the best "trade test" for grading colour defectives as fit or unfit for aircrew duties. Should standards be lowered it would be necessary to supplement the lantern with a quantitative test which should be related, if possible, to the role envisaged for the candidate.

INTRODUCTION

The colour vision requirements and selection methods for Royal Air Force aircrew, in use today, were adopted in 1950. The present study examines whether these standards are still relevant to the operational needs of the Royal Air Force in the 1970's.

METHOD

The investigation was mainly carried out in RAF Strike Command which is involved in most operational roles. Discussions and visits also took place within Air Support and Training Commands, the Army Air Corps, and with centres responsible for aircrew selection.

In the case of RAF Strike Command, discussions were held with staff officers responsible for the various roles, and visits were made at group headquarters concerned with maritime operations, air defence and strategic bombing. The views of the Central Trials and Tactics Organisation were also obtained. Operational stations representative of each role were visited, and individual crew members gave their views on the value of colour cues in their particular role. Aircraft cockpit assemblies were examined, and where feasible crews were accompanied on training sorties. Personal experience of mock emergencies was gained in the simulator.

RESULTS

COLOUR REQUIREMENTS COMMON TO MOST ROLES

<u>GROUND TO AIR SIGNALS</u>

1. VEREY LIGHTS (red/green/white/yellow/blue)

   ALDIS SIGNALLING LAMP (red/green/white)

Red and green are used in search and rescue, and in the rare event of complete loss of radio contact with ground control they would be used to indicate whether it is dangerous or safe to land. The other colours identify ground units to friendly aircraft. Verey lights may be fired in combination, i.e. two reds and one green in the same cartridge and can be difficult to see in bright hazy conditions. The Aldis lamp subtends, at distance, a very small angle on the retina, and although very bright it can be difficult to see unless accurately aligned on the aircraft.

2. SMOKE

   a. RAF (brown/white)

   b. ARMY (red/green/white/yellow/blue)

   Smoke is used as a marker to indicate targets, dropping zones and friendly units.

3. FLUORESCENT MATERIALS

   a. Dayglo - Orange

   b. Fluorescein - Greeny yellow dye

Dayglo is used for dinghy marking in search and rescue operations and by the Army to convey information to aircraft by varying the geometry of fabric panels.

Fluorescein is used as a marker in sea survival.

LANDING AIDS AND AIR SUPPORT MARKINGS

1. ANGLE OF DESCENT INDICATORS

a. VISUAL APPROACH SLOPE INDICATOR (VASI)

This is a device consisting of two sets of angled red and white lights separated on each side of the runway by 50 yards. The lights are very bright and can be seen up to 8 miles away in clear conditions. During the descent the pilot is on the correct glide path if both sets of lights look pink, or if the distant set is red and the near set white. In an emergency painted boards can be used instead of lights.

b. ANGLE OF APPROACH INDICATOR

This is an older device which is becoming obsolete. It uses the colours yellow, green and red. Pilots have reported confusion of the colours with other airfield lighting.

c. MIRROR LANDING DEVICES

The Royal Navy uses a landing device whereby the pilot, when making a correct descent, aligns a circle of white light "meatball" centrally between two horizontal datum bars of white light. Later versions of this use a yellow "meatball" and green datum lighting.

2. RUNWAY LIGHTING

a. The lights which indicate the lead in path to the runway are red or white.

b. The lights on the edge of the runway are white.

c. The lights on the centre line of modern runways are usually green, whereas older runways may use white lights. The most modern array has alternate red and white lights.

d. The lights on the threshold and end of the runway are transversely positioned red or green.

e. Taxiways on modern airfields have green centre lighting alone or the combinations of green and blue, or blue and amber on the taxiway edges.

f. Traffic lights are horizontally positioned red and green lights.

3. AIRFIELD IDENTIFICATION BEACONS

A flashing red beacon indicates a military airfield.

A flashing green beacon indicates a civil airfield.

A flashing green or white beacon indicates a civil airfield in Europe.

AIR TO GROUND SIGNALS

If it is necessary to indicate to a home base that an aircraft is friendly or that contact with the tower is lost, an Aldis lamp or a red flare may be used.

AIR TO AIR

1. ANTI COLLISION LIGHTS

These are flashing red or strobe white, sometimes reinforced for daytime use with Dayglo panels, although panels can have the effect of breaking up aircraft profiles.

2. NAVIGATION LIGHTS

The port side is indicated with a red light; the starboard side is indicated with a green light; whilst the tail of the aircraft has a white light. These lights are important in that they show whether an aircraft is approaching or receding. Many pilots consider that with modern high performance aircraft it may already be too late to take avoiding action if one is close enough to have appreciated these cues.

3. NATIONAL MARKINGS AND FLAGS

In times of emergency it is desirable that national markings be seen, as the same type of aircraft or ship may be used by hostile, neutral or friendly countries. In actual hostilities, due to the range of modern missiles, an aircraft - if not known to be in the area and friendly - would be attacked on radar or first sighting.

4. AIR TO AIR REFUELLING

The Victor tanker has Dayglo markings and presents an array of signal lights to the recipient. The colours red, amber and green are used and are differently positioned on the centre and wing pods.

A red light signals that the aircraft is approaching the tanker or must break away.

An amber light shows that the recipient is line astern.

A green light indicates that fuel is flowing and an amber light that the tanks are full.

The sequence green, amber and back to green conveys the information that 1,000 lbs of fuel have been given.

Many pilots state that they ignore the colour of the lights, relying instead on their position.

AIRCRAFT INTERIORS

1. COCKPIT LIGHTING

Many lights are used in the cockpit and these can be divided into three categories. Red lights indicate a hazard demanding immediate attention; amber lights indicate a lesser malfunction which if left unattended could lead to a major hazard; while blue, green or white lights confirm that a service is functioning. For example, in one aircraft a red flashing attention attracting light accompanied by a clanging bell in the headset indicates a major hazard. On looking to his left, the pilot sees the malfunction written on a panel backlit in red. The amber cautionary light panel is on the right with the legend of the minor malfunction also backlit. Attention is drawn by an amber flashing light not accompanied by a clanging bell. Emergency levers such as on the ejection seat are painted with yellow and black bands, and some gauges have coloured segments painted in red and green.

Aircrew appear to rely to a degree on the position of lights, rather than the actual colours, to know what is amiss.

Cockpit lighting in recent aircraft is integral tungsten white, colour temperature corrected "lunar" white, or red accompanied by flood lighting in white or red. Older aircraft may have ultra violet and red lighting. One possible hazard noted is that owing to the difficulty in seeing instruments, pilots frequently turn up red floodlighting to maximum brilliance. This could result in some fatigue of the red receptors and difficulty with VASI.

2. MAPS

The colouring of maps is of significance in flight planning. In flight the course will be confirmed by sighting landmarks such as towns, roads, railways, hills, woods, promontories etc. Spot heights are marked in figures, lessening the requirements for coloured contouring, while many other features of colour coding are duplicated by legends, figures or shapes.

Most navigators are able adequately to read maps in red cockpit lighting. This lends support to the value of cues, other than colour.

3. ELECTRONICS

Repairs to electronic equipment would not be undertaken in flight. The only servicing attempted would be minor, such as changing a fuse.

SPECIALISED ROLES

1. MARITIME

Search is primarily done by electronic devices. Visual sighting is by silhouette recognition which is seen before colours are appreciated, especially if a vessel is backlit. The sea provides a grey/green and white environment in northern waters against which ship colouring of grey, white and dirty rust blends well. The red funnel markings of some trawlers, and the green decks of Royal Naval ships are only appreciated when very close.

High speed vessels provide an obvious white wake, especially when moving at right angles to the white caps.

The strike role could involve recognition of national flags or markings, but in war an unknown ship in a potentially hostile area would be attacked long before markings could be seen, probably even before the silhouette was seen.

Search and rescue; the chromatic element of this is recognition of red and green Verey lights and the recognition of Fluorescein and Dayglo.

Navigators use Decca, Loran or Consol charts which have lattice lines in blue, red, green, brown and purple.

2. AIR DEFENCE

The aircraft is radar controlled to target, and missiles are fired before the target is within

visual range. In interrogation there is the need to recognise profiles by night and day with confirmatory evidence of national markings in day time.

3. LOW LEVEL STRIKE

Strike against enemy targets would always be at low level. The aircraft would fly to just outside enemy radar, and then descend to operating height and make a high speed approach to target. Collision avoidance radar is fitted but visual watch is also kept as a safeguard, and in order to check the low level navigation by sighting roads, bridges, railways etc. In operations opaque screens would cover all windows and no-one would look outside at all due to danger of flash blindness and retinal burns.

The maps preferred are topographical tactical charts which are relatively uncluttered.

4. TRANSPORT AND ARMED RECONNAISSANCE

There are no problems peculiar to this role.

5. CLOSE AIR SUPPORT TO GROUND TROOPS

This role includes the use of fixed wing, rotary wing and VTOL aircraft. They are radio controlled or rely on Verey, Smoke, Aldis or Dayglo panel geometry. They would have the need to recognise military formations, vehicles, tanks and terrain features. It is in this role of close air support that the greatest need exists for good colour acuity.

Camouflage markings are chosen to confuse the normal trichromat. The colour defective, in this respect, may therefore be at an advantage.

DISCUSSION

The approach used in this survey was to interview aircrew as to the importance of colour in their various roles, and to supplement this wherever possible by personal experience. It is realised that this approach has disadvantages, as it is difficult for the colour normal to envisage the problems faced by the colour defective. Also, that answers to questions may vary according to how the questions are phrased. Nevertheless this was the most practical approach, and a remarkable consistency of views was obtained from officers of different seniority engaged in widely differing tasks. The initial reaction of most officers was to regard a high degree of colour acuity as essential, but on analysing this view many were surprised at how little they really relied on colour as a paramount cue.

Visual perception is dependent on a great variety of different visual cues supplemented cortically by experience and intelligence. Much of the visual information may be duplicated by different cues, and it is this redundancy of information that gives an individual confidence in what he sees. If colour vision standards were lowered one of these cues would be removed and therefore the colour defective would be at some disadvantage, however small, with the colour normal.

The incidence of colour defectives in the British male population is approximately eight per cent and of these about half could be passed as fit for aircrew duties using the present test methods. Should colour entry standards be lowered in order to gain more recruits for aircrew duties, it would be necessary to change coloured signal standards internationally. It may be considered that this is not justified when the small gain in recruiting is weighed against the expense and the possible decrement in performance.

The present test methods of screening with the pseudo-isochromatic charts followed by grading defectives with the lantern are suitable for present standards. If standards were lowered it would be necessary to assess the defectives' deficiency quantitatively, and if possible relate this to the minimum requirements necessary for the safe and efficient execution of his role.

REFERENCE

1. P. L. Walraven. The fluctuation theory of colour discrimination.

ACKNOWLEDGEMENTS

My thanks are due to Wing Commander M. G. P. Venn RAF, DPMO (Av Med) RAF Strike Command for his help in the operational aspects of this study.

APPENDIX 1

TYPES OF COLOUR DEFECTIVE

Some degree of colour anomaly occurs with a mean frequency of approximately 1 in 12 in the British male population.

Colour vision is a function of the cones and therefore of photopic (day) vision. The rods, which cannot discriminate between colours, are responsible for scotopic (night) vision. The rods are maximally sensitive to shorter wave lengths in the blue-green region of the spectrum, peaking at about 500 nm. They are relatively insensitive to longer wavelengths at the red end of the spectrum.

According to the generally accepted Young-Helmholtz theory of colour vision, there are three classes of cone present maximally at the macula, in the ratio of 1 : 10 : 10. These cones have absorption peaks at about 440 nm (blue), 540 nm (green), 580 nm (red). A combination of these three primary colours in the correct proportions is seen as white light, and by varying the proportions and saturation any other colour can be matched. According to the work of Walraven, information from the three types of cone is analysed into three channels. A brightness channel which is the summation of brightness information from each cone, and two chromatic channels, a Red-Green and a Yellow (red+green)-Blue channel. It might, therefore, be more accurate to use the term double dichromats rather than normal trichromats.

Colour defectives are generally sub-divided into three main groups.

1. MONOCHROMATS: Complete absence of colour sensation.

   a. Rod - frequency 1 in 30,000. Associated with poor day visual acuity.

   b. Cone - frequency 1 in 100,000,000. Associated with good day and night visual acuity.

2. DICHROMATS: Require only two primaries to match all colours.

   a. Protanopes: 1 in 100. Lack red cones, therefore suffer a loss of brightness as well as absence of red sensation. This gives rise to red/green confusion.

   b. Deuteranopes: 1 in 100. Do not possess separate red and green cones but a single cone presumably containing both red and green pigments. There is no loss of brightness, but red/green confusion.

   c. Tritanopes: 1 in 13-65,000. Very rare, lack blue cones. The normal individual is tritanopic if the field of vision is small enough as the fovea centralis does not contain blue cones.

3. ANOMALOUS TRICHROMATS

   a. Protanomalous: 1 in 100 Require more red stimulation for a match than normal.

   b. Deuteranomalous: 1 in 20 Require more green stimulation for a match than the normal.

   c. Tritanomalous: Rare, but suggested to be 1 in 4,000. Require more blue stimulation for a match than the normal.

As can be seen from the above approximate figures, it is only with red green defectives we need be concerned.

As by far the majority of flying personnel are normal trichromats, it is important that any changes or additions to colour cues made for the minority should not confuse the majority.

APPENDIX II

REQUIREMENT FOR COLOUR ACUITY

It is important to reject the misleading term "Colour Blindness" and instead substitute the more descriptive phrase "Colour Defective". A noteworthy point is that even in the colour normal, one spectral wavelength does not always elicit the same colour response. This can be due to the effects of simultaneous and successive contrast, and with increasing age the deposition of yellow pigment in the lens.

It will also be of value to know how the various types of colour defective "see" different colours. (See Table Appendix II).

As will be appreciated the signal colours of red and green both in lights and flares could be made more obvious to the protonope and deuteranope by making the red more orange and the green more blue. To make confusion even less likely, further cues could be added such as a bar across a green light, but not on a red; or in flares by using a 2 star red and a one star green. (International standardisation would be required). The lattice lines on Decca, Loran or Consol charts could have an added shape coding.

Should the red signal colour be made more orange it would be necessary to abandon yellow light signals as these could be confused with the new red standard. It would also be necessary to ensure that white light was of a high colour temperature, as discrimination between a dim white light and the new red signal colour could be difficult.

If the green signal colour were made more blue it would be necessary to increase the power of the illuminating source. This would be necessary as the new filter would have a greater absorption factor, and in order to maintain visibility at its present level power consumption would have to be increased two to three times.

Yellow is not a vital signal colour in aviation, and the power of illuminating sources can be increased, but it is considered that the return in recruiting would not justify the international effort and cost involved.

Naming of Portions of a Continuous Luminous Spectrum by Red and Green Colour Defectives of Differing Severity

Normal Description	White	Dark Red	Red	Orange	Yellow	Yellow-Green	Green	Blue-Green	Blue	Black
Protanopia		dark grey	brown	dirty yellow	yellow	yellow-brown	grey	grey	blue	black
	white	brown	red	dark yellow	yellow	dirty yellow	grey	blue-green	blue	black
		dark red	red	orange	yellow	dirty yellow	orange	grey-green	blue	dark red or blue
Protanomaly		dark red	red	orange	yellow	light green	grey-green	green	blue	black
	white	dark brown	dark red	orange	yellow	brownish yellow	green	bluish	blue	black
Deuteranopia	white	brown	red	green	yellow	orange	brown-green	bluish green	blue	black
		dark brown	red	orange	yellow	dirty yellow	green	blue-green	blue	black
Deuteranomaly	white	dark red	red	orange	yellow	orange	greenish	blue	greenish blue	black
		brown	red	green	yellow	green	greenish	blue	blue	black

This information has been abridged from 'Table 5' page 32 of 'Diagnosis and Genetics of Defective Colour Vision' by H. Kalmus, First Edition 1965.

APPENDIX III

COLOUR TEST METHODS

1. PSEUDO-ISOCHROMATIC CHARTS

The best known of these are the Ishihara and H.R.R. plates. The Ishihara plates do not test for tritan defects but are of great value as a rapid screen for large numbers in eliminating all but minor degrees of red/green anomaly. In their use, light of the correct colour temperature is essential as is avoidance of oblique lighting which, due to differing degrees of ink gloss, could lead to spurious results. When inks begin to fade the plates must be replaced.

2. LANTERN TESTS

These are popular as "trade tests" with the armed forces, merchant marine and transport ministries of many nations, as they provide a practical test of a man's ability to recognise signal colours at different distances according to the angle subtended on the macula by the aperture used. The lantern tests are simple to use, and most examinees accept the justice of relating this test to their job. The Royal Air Force is at present engaged in sponsoring the development of a new lantern. This lantern should obviate the disadvantage of older lanterns in terms of colour temperature, cleanliness of small apertures and spectral characteristics of the filters.

3. FARNSWORTH MUNSELL 100 HUE TEST

This is a good, if laborious, test which involved grading of unsaturated colour caps in their natural order. It can be operated by unskilled people and gives the degree of colour deficiency in a quantative form.

4. LOVIBOND COLOUR VISION TESTER

This is a prototype machine which has not yet been fully evaluated. The candidate is required to match a central neutral grey light to a peripheral circle of randomised colours containing only one similar grey. The brightness of the colours is under the control of the candidate and the degree of saturation can be varied continuously by the examiner.

5. ANOMALOSCOPE

This is the most scientifically valuable instrument for colour vision testing, particularly in the anomalous trichromat. There are many versions but all consist basically in presenting the candidate with a split field in which he is required to match a selected colour in one half of the field by a mixture of two or more spectrally pure colours in the other half, the mixture used being read quantatively. Unfortunately it is expensive, bulky and requires skilled operators.

6. ROYAL AIR FORCE TEST METHODS

A candidate is screened with the Ishihara plates. If entirely correct he is graded colour normal and is passed fit for all roles. Should he fail the Ishihara test he must correctly name the signal colours red/green/white at all sizes of aperture on either the Martin or Giles Archer lantern and he is then graded colour abnormal but safe for aircrew duties.

DISCUSSION

NOTE: Following the presentation of his paper Wing Commander Brennan presented a survey of colour vision testing lanterns and their characteristics, and gave some information on the new RAF lantern which is currently under development.

CHEVALERAUD Il me semble que vous n'avez pas parlé du facteur "temps" dans la lanterne que vous êtes actuellement en train de mettre au point. Il me semble que le facteur "temps" intervient d'une façon importante et vous permet peut-être de sélectionner pour certaines fonctions des indiviuus que vous repousseriez pour d'autres fonctions. J'ai été étonné que vous ne retourniez pas ce facteur. Est-ce-que vous pouvez expliquer les raisons pour lesquelles vous n'avez pas retenu une répresentation de temps des feux colorés que vous présenterez aux sujets?

BRENNAN This is perfectly true and the matter is still under experiment. We have not decided whether to present the colours for, say, 5 seconds or whether to present them for 1 second and switch the lamp off, and then present the colours for another second and switch it off, and then present it another three times.

VOS I was happy to see the chromaticity data for the various lantern tests. I missed them, however, in your preprint. I should like to have them and I do not know where they are published.

BRENNAN I can certainly let you have them. No, they have not been published.

VOS I appreciate that in some ways it is always nice to see standardisation, but how much does it pay off? Are the results which you expect with the standardized lantern better for personnel selection than those obtained with a primitive setup? Have you any guarantee?

BRENNAN No, I have no guarantee.

TREDICI Is there any plan to really correlate your lantern, our lantern, or any other lantern, with the actual requirements of the job, whatever the job. This is really the crux of the matter as we now have more tests than we are able to utilise effectively. This is an aspect that we are trying to press.

BRENNAN It is not the intention to add yet another test. This is an attempt to improve on a lantern test. We are trying to make it a trade test with the additional benefit that you can detect anomalous vision. Both colours, by being fairly wide apart, are equally effective as a trade test because they fall within the boundaries which have been set up by the ICAO.

KURSCHNER Do you believe that under present day flying conditions it is still realistic to require a pilot or a tower controller to deduce from the position of the green and red navigation lights whether a plane is coming towards or going away from the observer.

BRENNAN Yes, I think it is important and you will appreciate if 2 aircraft are heading towards each other, without the pilots being able to appreciate whether their planes are converging or diverging then I think with high performance aircraft they are very likely to have a collision.

AIRCREW COLOR VISION REQUIREMENTS

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SUMMARY

Color vision requirements for aircrew are subject to much debate and little operational research. Previous studies by USAARL have identified a relatively high population of color defective aviators in Army aviation. A subsequent study revealed no statistical difference in accident rates between a selected population of color defectives and a matched sample of normals. The only significant difference demonstrated was between serious accidents in which the color normals were involved in a greater number of accidents (statistically significant) than color defectives. Operational testing of difficult cases will also be presented.

We ordinarily consider the male population to have either normal color vision or to be color-blind. Color-blind is a familiar but misleading description of a visual defect that describes the inability of certain observers to detect color differences which can be readily distinguished by a normal observer. Therefore, a more appropriate term is defective color vision. Numerous studies have established that among the European and American male population there are some eight percent of males who possess defective color vision. The borderline between normal and the initial stages of defective color vision is ill defined. Generally speaking, a defective observer, or one that has defective color vision, cannot be employed for making visual measurements with a colorimeter because he is unable to repeat these detailed matches with sufficient accuracy, and because his average readings are subject to wide variations as compared to their true value as seen by a normal. The defective color vision subject is also likely to be handicapped in color work generally since his description of the sample may not equal that given by a normal person and he will not be able to recognize errors in color quite so readily.

One of the real serious problems in the area of establishing color vision standards is the fact that investigations of the physiological mechanisms subserving human color vision have always been interdisciplinary in nature, i.e., they have been studied by psychophysicists, physicists, ophthalmologist, physiologists, anatomists, biochemists, biophysicists and bioengineers. This has no doubt come about because of the complex technological problems associated with the human mechanism for transferring one quanta of light energy to the brain with the resulting perceptual awareness. Thus, color vision is an unsolved mystery to those of us that should understand it. In talking about color vision to this group, I am reminded of the quotation that "the things that we understand least, we explain best to others". In any event most of the vision textbooks and the anatomy textbooks are a mixture of scientific fact, hypotheses, and the theories of the author that are as conflicting and biased as the opinions of the author selected as the authority. As a result, it takes rather diverse reading and study to have a reasonably comprehensive view of the subject. As a result the newcomer to this field has a tendency to grossly underestimate the complexity of this subject and to overestimate the value of his initial contributions. One thing is certain, there is a total lack of a nice theory to tidy this whole problem up and present it in a neatly wrapped package. The study of human color vision involves a very large number of disparate problems, that range from the physics and chemistry of the photoreceptive process to subjective perception.

The generally accepted classification of visual systems in terms of color vision are the normal and the defective. The normal has a wide range of spectral sensitivity from the shorter wavelengths around 400 nanometers through roughly 750 nanometers. The normal subject requires three (3) primary colors to match this total visual spectrum. Those color deficient or defective observers most nearly representing the normal are called anomalous trichromats. These trichromats will not accept certain normal color matches regardless of the variation of the normal eye that makes these matches, but they are still able to match every color in the visual spectrum with three (3) primary colors used by the normal. This is a most difficult diagnostic task to determine the degree of color anomaly because it is almost impossible to judge the impairment of color sensibility to chromatic differences in accord with the degree with which the matches of the anomalous trichromat differ from the normal matches. One type of anomalous trichromat is differentiated by an additional problem, his luminosity functions vary from other types of anomalous trichromats and also differ from the normal. The next level or more severe type of color defective is the dichromat. The monochromats are the most severe form of color defectives and are important in studies of color vision, but they are not important for the purposes of this paper. Monochromatics are considered too defective in both acuity and other problems to be satisfactory aviators and their identification is not difficult.

This brings us then to the problem of medically selecting aircrewmembers on the basis of color vision requirements. Ordinarily, tests for color defects are carried out for a particular purpose. They may be undertaken as a purely scientific investigation to discover the incidence and nature of the defect, or the tests are given for industrial or military task requirements, i.e., whether or not the individual is capable of performing certain types of work in which color discrimination is required. This is the case of aviation. Almost all medical standards specify a certain amount of color discrimination required for flight safety and mission accomplishment. The problem then is how to test whether or not a potential aircrewman is visually fitted for this type of work. Should we use the classic color tests used for separating normals and defectives, or should we give him an operational test in which he is asked to perform operations similar to those he would have to carry out in actual flight. If we select the latter, then the conditions of this test must accurately measure the requirements encountered in actual flight. If we give this second type of test, one which determines his work capability, then we must recognize that it does not necessarily indicate whether or not the applicant is color defective, but only whether or not he can satisfactorily perform certain color discriminations required by in-flight

operations. A complete diagnosis of color defective vision calls for the measurement of photopic sensitivity curves, spectral mixture data and wavelength discrimination with the aid of very elaborate spectroscopic equipment. One form of test employed to evaluate color vision (almost without exception) consists of a series of patterns of colored dots in patterns and relations that are designed to exceed the perceptual ability of the anomalous observer. Another form of test is the anomaloscope presenting a bipartite field color mixture requirement to the person being examined. The nature of the defect of this kind of test is usually indicated by the need of excess red or green in order to match a standard yellow.

Rather than discuss the infinite variables associated with the grading or rank ordering of the color defective it has been my impression for a long time that our applicants for aviation training do not have to be color perfect in order to be good pilots and fly safely. It is difficult to maintain the philosophy that pilot selection be continued according to those color vision tests that have been designed to select only those that are color perfect. It has long been our impression that few of the navigation, in-flight operation and airfield control procedures that are encountered in any modern aviation environment depend upon the color vision skill as they once did in the pre-electronic era. This is not a new concept to be presented to AGARD; in fact, Bouman and Walraven first made this recommendation in 1954. At the 1965 meeting of AGARD, we presented a paper entitled "Color Vision Deficiencies in Army Aviators" to substantiate this inductive conclusion. Due to the sensitivity of color vision testing methodology, examiners can and do fail to detect color anomalous observers, and conversely fail to accept normal observers. Because of these test difficulties, it was our opinion that a large number of Army aviators might in fact be color anomalous. Our hypothesis was confirmed as a result of the work done for this AGARD paper which revealed that about 4.5 percent of the US Army aviator population is color anomalous. This compares to the general male population which is about six (6) percent, the other two (2) percent being classified as deuteranopic, protanopic, tetartanopic, or monochromatic. This fairly large incidence of anomalous color vision among Army aviators reinforced our interest in the role of this anomally in the selection, training and flying safety.

Fourteen (14) color defective pilots were randomly selected from this population of known color defectives. Detailed analysis by colorimeter identified them as anomalous (mild to moderate) or protanomalous or deuteranomalous type. A matching sample of fourteen (14) pilots was then selected from a pilot population with normal color vision and matched with respect to age and total flight time. The accident record for each individual was examined to determine whether anomalous color vision in US Army aviators could be identified as a significant factor to flight safety. The results of this study are shown in Table I and Table II.

Table I shows the totals and means for age, flight hours, total accidents, serious accidents, and minor accidents for the color defectives. Table II shows this same information for the color normals. The accident data used were provided by the United States Army Board for Aviation Accident Research. Their classification scheme with regard to "serious" and "minor" accidents is:

a. Major - those accidents which result in total aircraft loss or cause substantial damage to major systems.

b. Minor - those accidents or incidents which result in a lesser amount of damage than those classified major.

Statistical tests including the nonparametric Mann Whitney U and the parametric $\underline{t}$ were performed on the accident data. All tests were one tailed with a confidence level of .90. This level of confidence was chosen over some higher level in order to provide more power. These tests yielded statistical significance between groups for serious accidents but not between groups for total and minor accidents. Thus, the null hypothesis stating that there was no difference between color defectives and normal was rejected only in the case of serious accidents. It can be seen from the tables that in this category color normals had more accidents than color defectives.

From a statistical as well as a practical viewpoint, the results of this investigation indicate that mild anomalous trichromats do as well and, it would appear, in some cases better than do color normals in terms of aircraft accidents. No consideration was given to forced landings and precautionary landings due to variables that control these experiences.

The Farnsworth Lantern is a color vision test which presents specially selected pairs of red, green and white light. It was developed for US Navy use by the late Commander Farnsworth in the early 1940's to minimize the number of color defective applicants disqualified for Navy positions for which color judgements were a critical operational task. All of the pseudoisochromatic plates used for color vision testing are designed to pass only normals and to fail all color defectives. Farnsworth designed his lantern to pass normals and that portion of the defective population which can make color discrimination adequate to certain Navy task requirements, i.e., mild anomalous trichromats. It is my considered opinion that the US Navy color vision requirements, for ship, air, and submarine, are not in fact different from Army aviation color vision requirements. It is too detailed a subject to review the development of Farnsworth lantern and its control for handling of the various types and degrees of color defectives. However, subsequent studies of the findings of the Farnsworth lantern reliability and validity data indicate that it does in fact pass the very mild color vision defectives and in fact fails the more severe color defectives. In addition to the Farnsworth lantern, however, there has to be one other final type of test used to determine whether or not an airplane pilot can in fact fly successfully and safely. Those who fail our isochromatic plate tests and are marginal on the Farnswrrth Lantern often happen to be aviators that have slipped by previous exams and therefore are students whom we already have initial training investments or aviators who have been flying for some time prior to detection. In these cases, we have elected to perform an in-flight evaluation of the aviators color vision.

These tests consist of in-flight tests to determine the candidates ability to read flight instruments (i.e., "in the green"), properly identify navigation light colors and direction of flight of other night traffic, and correctly identify (no errors) a random presentation of smoke grenades and control tower signal lights at a distance of one mile during VFR conditions.

Table I

COLOR DEFECTIVES

Age	Total Flight Hours	Total Accidents	Serious Accidents	Minor Accidents	*FL/PL
45	6220	0	0	0	0
45	4910	2	0	2	0
40	2000 (in 1965)	4	1	0	3
42	2680	0	0	0	0
34	4100	7	0	5	2
38	4112	0	0	0	0
36	2460	2	0	2	0
32	3220	3	0	0	3
32	1620	4	0	0	4
30	1320 (in 1967)	0	0	0	0
30	1230	0	0	0	0
29	2940	1	1	0	0
27	2040	0	0	0	0
25	2710	2	1	0	1
Totals:					
485	41562	25	3	9	13
Means:					
34.64	2968.71	1.79	.14	.64	.93

*Forced Landings/Precautionary Landings

Table II

COLOR NORMALS

Age	Total Flight Hours	Total Accidents	Serious Accidents	Minor Accidents	*FL/PL
47	6630	1	0	0	1
49	4930	0	0	0	0
40	1770	1	0	0	1
42	2610	3	1	2	0
37	4370	3	1	0	2
37	3990	2	0	1	1
35	2440	2	1	0	1
35	3190	2	1	0	1
29	1710	3	0	2	1
30	1330	4	2	2	0
31	1400	2	2	0	0
36	3000	0	0	0	0
31	2100	1	1	0	0
33	2720	0	0	0	0
Totals:					
512	42190	24	9	7	9
Means:					
36.57	3013.57	1.71	.64	.50	.64

*Forced Landings/Precautionary Landings

DISCUSSION

PERDRIEL Je crois effectivement que le sujet de l'orateur est excellent. Dans les cas douteux il est certain que seules les preuves en vol nous apportaient une réponse définitive sur l'aptitude des navigants. Je voudrais demander à l'orateur combien de fois par an par exemple il utilise ce procédé? Il est certain que c'est une demande que doivent faire les médecins de l'état-major pour disposer d'un avion, d'un équipage et des possibilités d'examen avec des feux colorés, si elles ne gênent pas certaines infrastructures. Alors, est-ce que la fréquence est suffisamment grande justement pour motiver une demande officielle d'utilisation de cet'e méthode dans les cas douteux?

BAILEY Yes, we do have aircraft available; in fact my laboratory has three. We have a JU 1 H helicopter, a single engine fixed wing Beaver, and a two engine fixed wing C-45. I would say that our tests average probably no more than four a year, roughly one every three months.

TREDICI We use the AOC and the Dvorine plates because of a supply rather than a scientific problem. They both have the same stock number and when we order one what we receive depends on what was on the shelf. I agree with you that the Farnsworth lantern is probably better than our CTT; it is simpler, and it does not have all the potential anomalies found with the Vernon. However, it would be very expensive to change lanterns in all our Flight Surgeons' offices throughout the world to this lantern which, I think, is rather overpriced. That is why we have not made a change at this point. I think we have some advantages with the CTT and it does give the degree of anomaly if you take the necessary time.

BAILEY The Farnsworth lantern costs about 670 dollars per copy and it has just a simple light bulb in the middle. I cannot understand why it is such a terribly expensive device.

CULVER Do you think it might be possible that a simple and a less expensive lantern could be developed. It could perhaps be modelled after the Farnsworth lantern and include the aspects that we have heard in some of the other papers at this meeting. We could than look to this as a standard among the various services for a final test?

BAILEY My answer is yes; I believe it could and I do not think we could ever get a simpler device than the Farnsworth lantern which is of a simple design and has the instructions written on the side; it is almost foolproof but it is not diagnostic. It could perhaps be married with yours so that it became of more diagnostic value. It might be worth investigating so that we could see if we could develop for less than, say $100, a lantern that was equally effective.

KURSCHNER Have you examined the 4.5% abnormal trichromates whom you mentioned in your paper, on the anomaloscope? If so, how did they behave in respect to abnormally increased colour contrast and variations of the adjustment range?

BAILEY Yes, we examined all of them prior to tristimulus colorimetric evaluation for colour mixture.

The use of the Nagel anomaloscope was as follows:

1. Pure red was presented in 1/2 the visual field and the subject requested to match it in colour and brightness.

2. Pure green was presented in the same manner. Brightness and colour naming were used foe diagnosis.

3. The match, if achieved in 1 or 2 above, establishes dichromacy. If a match is not made then a match of red with green against the yellow is made to establish the diagnosis of the type of anomaly, e.g. protanomalous, deuteranomalous. The range of red-green match was revised, but only for difficult diagnostic cases. In these cases large ranges of red-green were considered anomalous, e.g. a range of greater than 10 R/G units. Subjects were considered anomalous trichromates unless tri-stimulus colorimetric data luminosity curve data proved them to be normal. I do not recall any subjects presenting with abnormal colour vision who were reclassified as normal by subsequent colorimetric evaluation.

PREDICTING VISUAL PERFORMANCE IN AVIATORS (COLOR VISION)

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Before discussing the role of color vision tests as predictive indicators of flying task performance we should review briefly the whole concept of physical standards in the selection of personnel.

After assuring ourselves that their histories do not reveal any illness which might leave residual disability or recur again, we examine all our applicants very thoroughly, noting their height, weight, body build, cardio-respiratory status and other indicators of their general physical condition. We then require that they perform certain tasks involving sensory acuity of various types, and we even make a superficial attempt to estimate the level of their intelligence and conformity to what we think of as psychological norms. When selecting personnel for certain types of occupations we go even farther and conduct examinations which measure muscular strength and physical coordination. We then designate certain minimum acceptable scores on all these measurements and call them "physical standards".

Our assumption is that, all other things being equal, the aggregate scores which candidates achieve on these examinations are a reliable predictive correlate of their ability to perform the job for which they are being considered. For instance, we assume that an individual who has a minimum retinal perceptible separation of one minute (1') of arc (20/20 or 6/6 visual acuity) can "see better" than one who has a minimum separable angle of two minutes (2') or arc (20/40 or 6/12 visual acuity) and will therefore in the cockpit of an aircraft perform better those visual tasks involved in flying.

Our next step in logic is to assume that if we have more applicants than we have jobs, then we can maximize the likelihood of competent performance by applying our physical standards in such a way that a reasonable number of applicants will be designated "acceptable", while the rest will be rejected. This is a very rational hypothesis, and while we have never tested it in a properly controlled experimental fashion, it is an accepted and time-honored method of personnel selection. When the demand for personnel has been urgent it has been a simple thing to lower the standards, and then raise them again when the emergency has passed. It has been a workable, practical, flexible system; and there are no immediate plans to replace or abandon it.

The system itself is not without its inherent faults, however. For instance, when we come to the subject of aviation physical standards for color-vision, we find that there is not universal agreement, even among color-vision experts, as to what is the best color-vision test; and we even have some difficulty in agreeing on what is a good one.

For example, our Air Force uses primarily the 15-plate (including 1 demonstration plate) pseudo-isochromatic plates, but candidates who fail are further tested on the Color Threshhold Tester (CTT), and if they achieve a score of 50 correct out of 64 tries they are considered as having adequate color vision. Our Navy, on the other hand, will allow a passing score on any of the available sets of pseudo-isochromatic plates; and if all of these are failed, a passing score on the Farnsworth Lantern (FALANT) test will pass the candidate. We in the Army have required that for Class I standards the candidate must pass one of the sets of pseudo-isochromatic tests, but for Class II the Farnsworth Lantern or Color Threshhold Test will also suffice.

Other tests which have been proposed for general use, and which are sometimes used when available, are the Ishihara Color plates, the Dvorine Color plates, the colored-yarn test, the Farnsworth 15-hue test, the Farnsworth 100-hue test, and the anomaloscope. However, we have no physical standards for their results; so their results contribute little in any one case. The performance score of an individual on any one of these tests may not be consistent with his score on others, either because of the nature of his color-sense defect, because of the complexity of the psychophysical tasks involved in the particular test, or because the tests may not be measuring the same thing in all cases. Thus we have a situation in which some individuals will pass any such test, some individuals will fail all such tests, and a few individuals who will pass one or more but fail the rest.

Here is another potential fault which we must accept. I mentioned before that in selecting personnel on the basis of physical standards we assume that "all other things are equal". This category of "all other things" includes motivation, mental stability, specific aptitudes and the numerous other factors which we know influence job performance but which we do not have the time or ability to measure accurately or easily in large populations. When dealing with a population the size of the military-eligible segment of a country of 200,000,000 people, this is an assumption we feel safe in making. Although there may be a certain amount of wasted effort involved in waiting until later to eliminate those whose actual performance we find to be unacceptable, either during their training or even after they are trained, we believe that much more effort would be wasted in applying standards based on attempts to measure these factors (motivation, mental aptitude, etc.), since such measurements would be extremely time-consuming,relatively inaccurate, and not very easily adaptable to numerical scoring.

It is apparent, then, that if we use a single test for initial applicants, personnel in whom we have invested relatively little in the form of education and training; then having a single, relatively rigid standard is a simple and quick way to help get on with the selection of personnel whom we will subsequently educate and train. But there are some individuals who are already trained in aviation, and still other individuals who are already trained in one area but whose value will be further enhanced by training them in aviation as well; and to apply a single criterion for color-vision to these people, especially since

we admit that there is probably no single good criterion to apply, may not be appropriate. Therefore, when personnel in these categories do not achieve passing scores on our routine color-vision tests, our approach to them has not been quite so dogmatic or rigid. We have taken the approach that as long as this group is small enough we can spend the time it requires to apply to them an appropriate experimental model of color-vision tasks in flying, observe their performance of these experimental tasks well enough to score them in a meaningful fashion; and even further, make an intelligent recommendation about their future training or use based on this score. We believe we can make a good experimental model of the color-vision tasks involved in flying. Accordingly, we have designed as part of our Aeromedical In-flight Evaluation Program, a battery of color-vision tests which consists of the following:

1. Identify the color of signal-lights (Aldis Lantern, or "Biscuit Gun,") directed at the aircraft from the tower, using the colors red, white and green. This test is performed under both day and night flying conditions, including a sunrise or sunset condition with the rays of the sun providing significant interference at certain angles.

2. Identify the color of smoke from signal grenades thrown on the ground, using the colors red, white, green, yellow, red, and violet, with the candidate flying his aircraft at an altitude of approximately 500 feet.

3. Identify color-coded lights on run-ways (white), taxi-ways (blue) approach ends (green), and departure ends (red).

4. Identify the colors of the beacons at airfields for fixed-wing (green/white) and rotary wing (white/white) aircraft.

5. Identify the colors of lights on other aircraft as to right wing-tip (red), left wing-tip (green), and tail (white); so as to be able to deduce their direction of flight.

The performance of the candidate on these tests is scored against the performance of personnel whose color-vision is presumed to be normal. If they perform in a normal fashion, regardless of their scores on the conventional color-vision tests, they are allowed to fly unrestricted. If their color-vision is abnormal by these criteria, then they are restricted to flying with a co-pilot whose color-vision is normal or not allowed to fly at all, depending on the military requirement for them to fly in the first place.

Our recorded experience with this battery of tests as part of an aeromedical in-flight evaluation goes back only about three years. Before that time we did not officially recognize exceptions to failures of the clinical tests and extended no waivers of flying restrictions based upon such failures. Since then, however, we have had occasion to require performance of the complete battery on 12 aviators. Our experience is recorded chronologically below:

Pt(candidate)	Date of Evaluation	Clinical test scores	Performance	Disposition
1. DBL(1LT)	Jan 69	14 AOC-pass 4/14(f) CTT-pass 54/64(p) Yarn-43/43(p)	Smoke-100% Lights-100%	Waiver
2. HLG(CW/2)	Jun 69	14 AOC-"fail" FALANT-"fail" CTT-"fail"	Smoke-100% Lights-100%	Waiver
3. RAB(CPT)	Sep 69	14 AOC-pass 8/14(f) CTT-45/64(f)	Smoke-100% Lights-100%	Waiver
4. GRA(CPT)	Sep 69	14 AOC-pass 10/14(f)	Smoke-missed green Lights-missed green	No Waiver Disqualified
5. SMB(CW/2)	Jun 70	14 AOC-pass 8/14(f) Dvorine-pass 9/14(f)	Lights-100% Smoke-100%	Waiver
6. JKM(CPT)	Nov 70	14 AOC-pass 8/14(f) FALANT pass 7/9(f) CTT-48/64(f)	Smoke-100% Lights-100%	Waiver
7. BJF(CW/4)	Jan 71	14 AOC-pass 3/14(f) Dvorine-pass 9/14(f) CTT-pass 47/64(f)	Smoke-100% Lights-100%	Waiver
8. WLM(CPT)	Mar 71	14 AOC-pass 5/14(f) FALANT-pass 6/9(f)	Smoke-100% Lights-100%	Waiver
9. JDP(CPT)	Mar 71	14 AOC-pass 7/14(f)	Smoke-100% Lights-100%	Waiver
10. TWT(CW/2)	Jul 71	14 AOC-pass 8/14(f) FALANT-pass 5/9(f)	Smoke-100% Lights-100%	Waiver

11. WJL(CPT)	Jul 71	14 AOC-pass 8/14(f) FALANT-"fail"	Smoke-100% Lights-100%	Waiver
12. JCN(MAJ)	Oct 71	14 AOC-pass 9/14(f) FALANT-"pass"	Smoke-100% Lights-100%	Waiver

In so small a group it is most difficult to determine, based on accident rates, whether the performance of flying duties has been in any way degraded by any existing defects in color-vision. Certainly we do not have enough retrospective information to even obtain a hint of the answer to that question; and a prospective study to obtain that information, at least within any reliable statistical limits, will probably take several decades to carry out. Of course, we do keep records on these personnel, hoping to detect even the slightest difference in accident rates between them and their peers; but meanwhile we believe we have taken, on the basis of logic and rationale alone, the best approach to selecting those individuals whose color-vision will allow them to perform flying tasks involving color-dependent decisions and restricting or eliminating those who truly are defective from a practical point of view.

DISCUSSION

TREDICI

Really what you said is that your "real world" tests are more lenient than the laboratory tests because you reversed 1 out of 12. I think that what you need is a test in the clinical laboratory that you can equate to real life thus bringing the "real world" into the laboratory without the need to go flying to obtain it. We have a colour threshold tester and I am going to look into it more closely because this aspect had been thought of in its design. However we have left it gathering dust for so long that I do not think we are utilizing it to the best possible advantage. This device has a capability of presenting "real world" situations by the use of various gradings. It uses an aviation signal light type of filtration, as does the Farnsworth, but it is not as critical. However, the major problem is how to equate the "real world" and the laboratory; just how low or high high on a scale must people go so as to equate with the "real world". The "real world" would, for example, be the "biscuit gun", am I correct?

APPLETON

The factors would include, among others, the "biscuit gun", runway lights, the effects of fog and smoke.

TREDICI

Therefore you would have to equate the entire set of factors to something more simple in the laboratory.

APPLETON

Wing Commander Brennan has already referred to this, particularly when he talked about the quality of the colour, and the standards to which lights are going to confirm on the ground; we need to make our tests conform to those numbers in quality, saturation, wave lengths and the other ICAO requirements. This gives us something to aim for. If the colour threshold tester meets those criteria and matches the ICAO-standards closely enough the next problem is how readily available and how costly will the colour threshold tester be? The best tests, if one is going to say that the plates are not the best tests as many have said here today, are also the most expensive tests, and we must determine in which way we are to go. This question is still not resolved.

CHEVALERAUD

Je suis étonné que, jusqu'à maintenant, nous parlions toujours de la vision des couleurs sous des conditions normales. Or, un navigant ne se trouve jamais sous des conditions normales. Il est fatigué, il a été soumis à une anoxémie relative, il est soumis en permanence à la vibration, il est soumis à des bruits, à des sons et à des infra-sons. Or, la vision chromatique chez un sujet normal est perturbée par tous ces facteurs d'agression extérieure en navigant et nous savons également que tout sujet, porteur d'une anomalie du sens chromatique, va connaître une décroissance de la sensibilité chromatique encore plus important qu'un sujet normal.

Je voudrais demander au Colonel Bailey et au Colonel Appleton, si les tests qu'ils proposent en vol, sont des test pour lesquels ils previennent, si vous voulez, les sujets qui devront y être soumis, est-ce que ces sujets savent qu'ils ont tel jour, telle heure, tel test à faire, est-ce qu'on les met vraiment dans les plus mauvaises conditions où ils risquent un jour de se trouver. Si vous répondez favorablement: dans les plus mauvaises conditions, je pense, qu'alors on continuera de les laisser voler. Mais dans d'autres cas je ne vois pas pourquoi on continuerait de les laisser voler.

APPLETON

That is a very good question and I like to share the answer with Colonel Bailey. I would say that this raises other questions. Is our test stressful enougn and if not, are we creating an adequate laboratory model or an experimental model of stress. What is the general stress surrounding our tests? I think they are fairly stressful.

BAILEY

In the first place our subjects were never told that they were going to get a flight test. They were merely told to report to the laboratory and then they were taken straight out to the aircraft which was soon airborne. The only requirement is that the test is given in daytime because the daytime requirements for identification are much more severe than they are at night, because of contrast. All that we required were the weather minima to get up and get down. The flight plan was visual and as long as VFR conditions prevail, we go. Sometimes the flight is rough, sometimes nice, sometimes in the morning, sometimes in the afternoon, without any prearrangement. It may be done, for example, when the subject has already flown 8, 12, or 2 hours, or possibly has been on leave for 2 weeks.

The other point that I would like to make is that I think the Farnsworth lantern, because of its design, represents an ideal test because what we are looking at is a real test of the visual mechanism in relation to its operational role, rather than a test that has ICAO red or some other colour. So long as it does the job of identification of the visual system function I am not perturbed about the brand of the filters. The important thing is the end result which is, I believe, well established with the Farnsworth lantern and also with the Air Force lantern.

APPLETON

A point that has just come back to me is that Professor Chevaleraud stated that a stress in the aviator aggravates his colour deficiency. if he has one. I would like to ask if this is true or whether a colour deficiency is just as deficient in an unstressed as in a stressed individual. Will stress aggravate the decrement in his performance which is caused by a colour deficiency? I do not know of any data to support the contention that a colour deficient individual has an anomaly which is aggravated by stress.

PERDRIEL

Je pense effectivement que certains "stress" peuvent intervenir pour diminuer la capacité chromatique des aviateurs et notamment les bruits. Avec le Médecin Général Grognot nous avons put démontrer que l'audition, pendant 5 minutes, d'un bruit de 105 à 110 décibels, entraînait un rétrécissement du champ visuel pour le rouge, une diminution de la rapidité de la perception du relief avec de plus une réduction de la capacité visuelle nocturne.

BAILEY

I would just like to say that apparently we have been doing this testing correctly because we do not have an aircraft in the US Army that has a noise level of less than 110 dB.

BRENNAN

I would like to make the point to Colonel Bailey that we chose ICAO regulations because these are the standards to which all aviation signal lights must conform. It is thus not a matter of a particular manufacturer's glass. All aviation signal lights throughout the world must conform to these regulations if civil aircraft are to use the airfields. I would like to know now many centres you have in the United States for testing aircrews? I appreciate the cost aspect of the Farnsworth lantern but your testing could be done in major centres. It would also be more reliable to have an ophtalmologist performing the testing rather than a technician.

APPLETON

We do not have centres for initial entry into the system, instead there are many points of entry. Candidates eventually get their training at either one of two centres, but by that time there is a considerable investment in them. What we need is a tes which is inexpensive, readily available, easy to apply correctly and hard to apply incorrectly.

HELICOPTER FLYING AND COLOUR VISION

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SUMMARY

Colour vision and flying have always given rise to some problem areas, especially where some individuals are colour defective. When these problems are encountered in low level helicopter flying, under poor light and in featureless terrain difficulties arise where colours have to be used for information presentation and to isolate certain items of information. Instrument lighting, map colours and markings can all become problem areas when the operators colour vision is abnormal. Differences are found in methods of colour vision testing. The use of coloured smokes against varying backgrounds can lead to mistakes, as can wiring diagrams and wire markings. Research is necessary in this operational environment to enable colour abnormals to work safely.

This paper was requested to be given at this particular meeting, as one which might be of interest and value.

It is very difficult to 100% black and white about a subject on which little is really known from an operational point of view. The comments made in the paper can be interpreted across the whole field of flying, although being discussed primarily for the helicopter user.

The illustration of such a paper is very difficult, because it cannot be known if all the audience are colour normals. If as suspected this is not the case, then the problems outlined may be better understood by the colour abnormals. A colour normal is understood as one who can read without mistake all of the ISHIHARA plates. How can a colour normal fully understand and appreciate the problems of the colour abnormal? Illustrations made by using colour filters do not really help. The technical problems involved in producing pictures with various colours toned down, removed, or tinted out are very difficult.

From a descriptive point of view, the use of colour must be limited, for not all colours are appear the same to all people. Only the most basic colours should be used, all shades of reds and greens, should be avoided. The colour range of the helicopter user must involve all colours with more emphasis on the red/brown/green part of that range in a terrain operation. This is just the colour area where the majority of defectives are found. The woods, mountains and plainlands of N. Europe have all shades of these particular colours. Why must the helicopter pilot be able to distinguish colour in this type of terrain? To direct missile or gun fire, relaying terrain description back to base did in the airborne command post role.

If there are no prominent objects to relate to, then the observer may be forced to use colour. Colour does, however, change, both with light intensity and saturation. Mist and other smokes can affect such factors. Shadows can produce a marked colour difference, and someone with a colour defect could wrongly describe objects or even miss targets under these conditions. Under shadow conditions, colours can be mistaken for shadows and this can be illustrated.

The problem is made generally worse under low light conditions for all users. The helicopter pilot cannot have a cockpit bathed in white light. Apart from making him a good target, he cannot use this night vision for outside reference, landing, night description for ground troops etc. He must then use red light. This has been argued about for a long time. Under red light conditions, maps using red, to mark danger areas, roads, boundaries etc can become confusing. Instruments can be misread if they are not designed with the correct coloured illuminant, for the same reasons. Much work needs to be done in this field, for someone with a colour vision defect may compound existing problems. This applies to colour normals as well, in operational areas not well known to the pilot.

If colour is the main source of information to the pilot, what is he to do. Smoke markers in featureless terrain must be very colour contrasting, orange against green etc. It can easily be illustrated, that what is initially a contrasting yellow smoke against a brown background, very soon, in a matter of 5 to 10 seconds, mixes and blends with the background. When smoke is used in snow conditions as a marker and for wind direction the colour may not be of any relevance, but for landing sites of the colour range already mentioned, the smoke must be very different when viewed against its background even after 10-30 seconds. Desaturation by other smokes, dust and mist must also be considered.

Camouflage must work for everyone, and colours are of interest in this field of use and can present problems. The use of mixed colours and broken lines avoids some of the problems. A colour defective person may be very useful in some conditions detecting camouflaged vehicles where colour is the main feature, especially when it does not match completely, the background for which it was intended.

Some clinicians know a great deal about colour defectives, but this is not the case in the low level tactical military situation, where little is known and understood of the problems of these people.

A few cases may be of interest. There are probably quite a few pilots who get through the screening processes, by knowing their problem and being able to get round it. They are however at risk in certain environments when the full colour range is required. One such pilot who somehow got through the screening system, was found out because he could not see the red lines on maps, especially under poor light conditions. This is of course dangerous, especially on a moving map display where the pilot may be unfamiliar with the area into which he is flying. Roads, danger areas and boundaries may be marked as red lines.

Chinagraph markings on maps and overlays may also be missed. A waxy colour pen on a plastic shiny surface can be difficult enough to see normally, so it can be understood how a colour abnormal might miss it altogether. This is relevant in the air when maps are being marked with positions etc as an updating process, as the situation moves along in time.

The outside reference problem is not so difficult if the objects to be referred to stand out against the background. Providing this factor is always remembered, then the problem is not so serious. This applies to aircraft markings ground panels, danger points, "do not touch" and "avoid" markers. It is not always the colour that matters, but the contrast with the background, its relevant size and above all aircrew education. This applies to letters, figures and all manner of markings and colours should be avoided where possible.

Groundcrew are as important as aircrew in this respect. In a relatively small operating force, the outstanding cases are remembered. A helicopter engineer was on a long engineering course. He had to date been primarily concerned with airframes and engines, but the course required him to learn electronics. He was referred as he was unable to read "Wiring flow diagrams in servicing schedules". These were in colours, a variety of pastel shades. He also was found to have difficulty in sorting out the real wires in wiring compartments, due to their colour markings. On examination he was found to have a severe degree of red/green colour blindness, and he had to leave the Service. Within a month an identical case was presented with the same result.

In conclusion here are ~~some~~ suggested solutions.

Colours should be avoided in describing terrain, but one must remember that this can be very difficult under poor light in featureless areas. Markers, indicators, lights etc., should always be used against vividly contrasting backgrounds and the users properly educated. Maps and their markings should be studied with a view to preventing colour mistakes occurring. Diagrams of wiring, the wires themselves, servicing schedules and all manner of charts and diagrams should be studied to ensure that people with colour vision problems will not make mistakes using them.

It must be further concluded from these few examples, there are many more, that where colour is used to highlight certain areas of information presentation, and in some cases isolate that information, only colour normals should be selected for those tasks.

If this is to be the case, then in order to select these colour normals, a more reliable test method is required, for many get selected wrongly now, due to poor application of the existing test methods.

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DISCUSSION

KURSCHNER I have two questions:

1) You mentioned a pilot who could not recognize the lines on his map. With what colour disturbance was he afflicted?

2) What was the colour deficiency of the helicopter mechanic who could not read the connection diagram?

PERRY 1) He had an element of red/colour blindness.

2) He was almost totally green blind.

I would like to emphasize a point in dealing with terrain description which is that a pilot reporting to ground should avoid, if possible, using colour descriptions unless we can find the hypothetical colour vision analyser which will ensure that all personnel have the same quality of colour vision and thus identify all colours in the same way. It is not, however, practicable to go to black and white, solely, as there are situations in which nothing else but colours can be used.

COLOR VISION REQUIREMENTS FOR AIR CREW PERSONNEL OF THE FUTURE*

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Color has unique value as a means of coding visually presented information. This has been shown by experimental evaluations of alternate coding methods, such as pattern, size, intensity and flash rate. A reduction in color vision selection standards for flight personnel, such as the pilot, would require the replacement of color with other and potentially less efficient visual coding methods. Such a change would restrict the visual display choices available to the designers of future information presentation equipment, both airborne and ground. An examination of past trends and current equipment development indicates that the use of color for coding information used by flight personnel will probably be increasing rather than decreasing in the future.

INTRODUCTION

Since the early days of aviation, normal, or near normal, color vision has been a requirement for pilots and some other crew members. Similarly it has been customary to require railroad engineers and certain maritime personnel to be able to pass some type of color vision test. Although color vision is useful for general visual activities, such as finding military targets, its primary value is for reception of color-coded information. Other papers on this program will, I assume, discuss the types of information transmitted to the pilot by means of color coding. My purpose in this paper is to show that color has unique value for such coding of important information, and that other possible coding methods are much less satisfactory. Also, the potential uses of color-coded information displayed to air crew members appear to be increasing. If the current requirements for air crew color vision were deleted, or substantially reduced, there would need to be a concurrent program to replace current color coded information displays with other less satisfactory display methods. Also, designers of future aviation information display systems would be denied the use of an important sensory channel that is optimum for many display purposes.

EVALUATION OF COLOR FOR CODING OF INFORMATION

Visually presented information can be coded in a variety of ways not involving the use of color. Alternate methods most commonly used in aviation are numerals and letters (alphanumerics), geometric or pictorial shapes, and flash patterns. A comparison among these and still other coding methods for display of information was made by Grether and Baker (1). Their overall comparison of different coding methods is summarized in Table 1. There is good reason why color is placed at the top of the list in this table. For coding of qualitative information into a limited number of categories, color is superior to any other available method of presentation.

The unique value of color for coding results from several properties:

(1) Up to 10 different colors (code steps, in Table 1) can be identified on an absolute basis. The number is much lower for other visual parameters, such as area, length, or brightness.

(2) Identification of the code is faster for colors than for other competitive coding methods. Coding by flash sequence or rate is very slow by comparison, since some time must elapse for transmission of the code.

(3) Unlike all other means except intensity and flash sequence or rate, colors can be presented as point sources, thus occupying minimal display space.

(4) The physical means of producing color are often much simpler than for other coding methods.

*The research reported in this paper was conducted by personnel of the Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. This paper has been identified by Aerospace Medical Research Laboratory as AMRL-TR-71-116. Further reproduction is authorized to satisfy needs of the U. S. Government.

COMPARISON OF COLOR AND SHAPE CODING

From the comparison of different visual coding methods it appears that for general purposes, there is only one other visual parameter which compares at all favorably with color. This is visual pattern in the form of numerals or letters, geometric patterns, or pictorial shapes. Such pattern codes are widely used, and for some purposes have advantages over color, as shown in Table 1. If the number of categories is very large, or if quantitative information must be transmitted, numerals and letters, and pictorial shapes are superior.

On the other hand, for coding of qualitative information into 10 or less categories, color coding is clearly superior, and this has been amply demonstrated in experimental studies by Ericksen (2), Green and Anderson (3), Hitt (4), Christner and Ray (5), Smith et al. (6,7,8,9) and Brooks (10). Some samples of the experimental data will indicate the degree of superiority of color over pattern coding. The first sample is from a study by Smith (6) in which subjects were required to search a field containing three-digit numbers, appearing in five different colors (red, green, blue, orange and white). The subject's task was to search for a specific number. Fig. 1 shows the time taken to find the target number when the color was known by the subject, and when it was unknown. For this task the use of color to code the targets into five categories greatly reduced the required search time. When the target color was known the subjects searched through the 100 targets in about the time otherwise required for 20 targets. It appears that the subjects were able to ignore all other colors, and searched only the 20 targets of the same color.

In a study by Smith and Thomas (7), the targets consisted of different shapes. There were five geometric forms, five military symbols, or five aircraft shapes. These were presented in five different colors - green, blue, white, red and yellow. Each test array consisted of 20, 60, or 100 such shapes. On some trials the subject's task was to count the number of targets of a certain shape in the total array. On other trials he counted the number of targets of a specified color. Fig. 2 shows the average time required to count the targets classified in different ways. Counting targets of a certain color was much faster than counting targets of a certain shape. Fig. 3 shows data from the same study for the percent of trials on which counting errors were made, and these were much lower for the count based on color by comparison with the three shape classes.

Aside from the experimental evidence that color coding gives faster and more accurate responses, pattern or shape coding is unsuitable for many applications because of surface area required for a pattern to be identifiable. One of the common uses of color is for long distance signalling. Navigation lights on aircraft and ships are examples of such use of color. Here the colored light is little more than a point source as seen by the observer. To accomplish the same signalling purpose by use of patterns would require prohibitively large displays.

FUTURE REQUIREMENTS FOR COLOR CODING

Looking to the future, there are indications that requirements for color coding of information used by air crew members will increase rather than decline. Over the past two decades there has been a general increase in the total amount of visual information provided to the pilot and other air crew members. Along with this has been increased use of color coding on cockpit displays, to aid the user in separating out the desired information. During the same period new ground lighting systems have come into use for providing runway approach and landing guidance. Some of these ground systems use color-coded lights.

It is quite likely that these trends toward increasing use of color will continue, particularly when we consider some of the newer display techniques that will probably be found in future cockpits. One such technique is electroluminescent lighting, which consists of flat plates that become luminous when activated electrically. The luminance level is proportional to the electrical voltage. A wide choice of colors is possible, the color being controlled in the original manufacture of the plate. It is not possible to control the color of the electroluminescent plate by means of the electrical signals fed to it. However, a plate can be divided into small areas, each of a different color. The choice of color then can be made electrically by choosing the area that is to be activated.

Electroluminescent lighting has many desirable characteristics for lighting instruments, control panels, warning panels, and other cockpit display systems. Much of its value comes from the variety of colors that can be presented to convey different types of coded information. Electroluminescent lighting was used in the crew compartments of the Apollo space vehicles, and will surely be used in crew stations of most future military aircraft.

Another display technique that appears to be destined for increasing use is what is usually referred to as a "heads-up display." This display is a further development of the well known reflecting gun sight which projects a reticle and aim point onto the windshield or other transparent surface in the pilot's forward line of sight. The markings on this display are focussed at infinity, and appear superimposed over the sky or terrain seen through the windshield. Commonly presented on a heads-up display are aircraft attitude, airspeed and other flight data useful to a pilot while he is looking outside, as in an approach to a landing. In such a display it is most helpful to have markings appear in different colors to identify their meaning to the pilot.

Still another class of colored displays that may be found in future cockpits are multicolored cathode ray tubes. These could be color television tubes, storage tubes, or other types of tubes capable of presenting a variety of colors. On such displays color would be quite useful for identifying different classes of information for the observer.

SUMMARY AND CONCLUSIONS

Color vision is an important sensory channel through which pilots and other air crew members receive visually presented information. Principally, this is qualitative information coded into a small number of categories. For presenting this type of information color coding has unique value. There are no other visual coding dimensions, such as pattern or flash rate, which can match color coding in terms of speed and accuracy of response, number of identifiable categories, simplicity, and compactness of the display. A reduction or elimination of color vision selection standards would require that many current color-coded displays be replaced, using less efficient coding techniques.

A look towards the future suggests that the use of color-coded displays will increase rather than diminish. New display techniques coming into use, particularly electroluminescent lighting and heads-up displays, gain much of their value from color coding.

If color vision selection standards were reduced or eliminated, this would add only about 5% to the available population of air crew candidates. But such an action would deny to the other 95% a unique and unequaled channel for display of flight information.

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Table 1. Comparison of Coding Methods, From Grether and Baker (1)

Code	Number of Code Steps* Maximum	Recommended	Evaluation	
Color				
Lights	10	3	Good	Location time short. Little space required. Good for qualitative coding. Larger alphabets can be achieved by combining saturation and brightness with the color code. Ambient illumination not critical factor.
Surfaces	50	9	Good	Same as above except ambient illumination must be controlled. Has broad application.
Shapes				
Numerals & Letters	-Unlimited-			Location time longer than for color or pictorial shapes. Requires good resolution. Useful for quantitative and qualitative coding. Certain symbols easily confused.
Geometric	15	5	Fair	Memory required to decode. Requires good resolution.
Pictorial	30	10	Good	Allows direct association for decoding. Requires good resolution. Good for qualitative coding only.
Magnitude				
Area	6	3	Fair	Requires large symbol space. Location time good.
Length	6	3	Fair	Interferes with other signals. Ambient illumination must be controlled.
Brightness	4	2	Poor	Requires large symbol space. Good for limited applications.
Visual Number	6	4	Fair	Requires large symbol space. Limited application.
Frequency	4	2	Poor	Distracting. Has merit when attention is demanded.
Stereo-Depth	4	2	Poor	Limits population of users. Highly limited application difficult to instrument.
Inclination	24	12	Good	Good for limited application. Recommended for quantitative code only.
Compound Codes	-Unlimited-		Good	Provides for large alphabets for complex information. Allows compounding of qualitative and quantitative codes.

*The maximum number assumes a high training and use level of the code. Also a 5% error in decoding must be expected. The recommended number assumes operational conditions and a need for high accuracy.

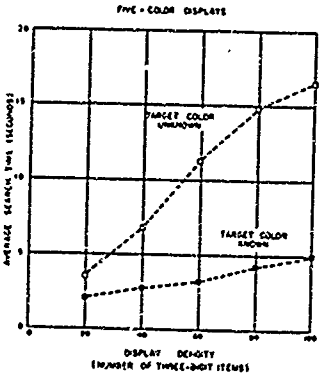

Fig. 1 Search time as a function of display density with knowledge of target color as a parameter.

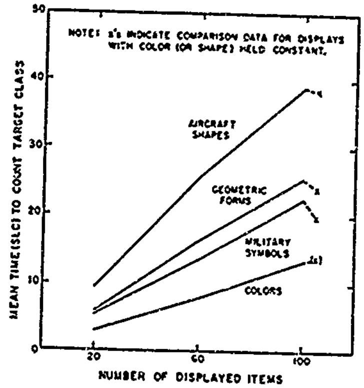

Fig. 2 Average counting time as a function of display density, comparing color coding with the three shape codes.

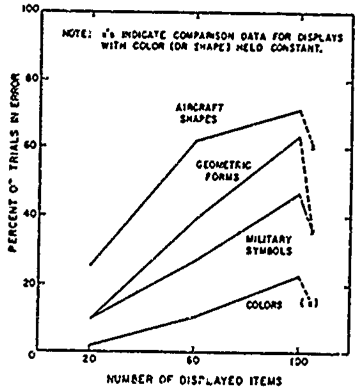

Fig. 3 Counting errors as a function of display density, comparing color coding with the three shape codes.

DISCUSSION

TREDICI — I agree with all those points since I made many of them earlier but I wonder if there are data to show how colour vision defectives operate at close ranges, for example when using equipment. This is a matter of feet (2 or 3 ft) versus what we have been talking about today which is nearer infinity. At close ranges they can control that environment in terms of saturation, brightness, etc. Do you know of anyone who has tried some defectives in this environment?

GRETHER — No, I do not recall any actual experiments on this. However, I was also referring to lights on the ground and on other aircraft which can be at quite a distance and which could be very small point sources. As it stands now the number of colours used in cockpits is usually rather small, approximately 4, often less. I think it is quite understandable that a deuteranomalous individual could adequately discriminate among the limited numbers of colours we use in our present coding and could work with this code. Protanopes and deuteranopes, as we heard this morning, would have great difficulties even with the limited number of colours we now use.

WHITESIDE — You were talking about the relationship of the coding compared to the use of the colour itself. But there is one circumstance in which you would probably agree that coding could be useful. I refer to the use of an identification beacon which could be flashing to identify it from another of the same colour which might be steady. Specifically, I am thinking of the possibility which had been raised in the International Committee of the Red Cross that ambulance aircraft, which are protected by the Red Cross Convention, might exhibit a blue anti-collision light instead of the conventional red light used on other aircraft. It had also been suggested that the blue light be made to occult irregularly, in groups of two for example, instead of flashing regularly. This would also help to identify the light at distances at which blue cannot be identified.

GRETHER — That kind of a code is, I am sure, much more difficult for a person to use than just a plain colour, particularly when you have a regular flashing or defined flashing patterns or an irregular pattern of flash to identify it as one of several. This would be very difficult and it would take time to observe the flashes and work out the significance of the code.

VOS — I would like to point out that some of the speakers appear to me to strongly disagree. Some say do not use colours, the others say use more colour.

GRETHER — Colour has real advantages and can do things in coding that you cannot do nearly so well in any other way. Therefore we need to preserve the colour vision capability of our aircrew so that we can use most efficiently this means of transmitting information to them.

HEYNEMANN — A propos des exigences concernant la vision des couleurs des pilotes des aéronefs futurs il me semble qu'il faut poser deux problèmes bien distincts:

1) La perception des signaux lumineux colorés.

   Avec l'augmentation croissante de la vitesse des aéronefs, la tendance est de demander une portée toujours plus grande pour les feux de signalisation en vol; la tendance est donc de remplacer les signaux colorés par des signaux blancs, les filtres colorés quels qu'ils soient absorbant une quantité importante du flux lumineux de la source. A condition que les feux de signalisation très intenses soient montés sur les aéronefs à des emplacements choisis convenablement pour que le pilote ne soit pas gêné par ses propres feux. Ces feux deviendront blancs dans un avenir très proche. Il n'est donc plus question de code de couleurs pour ce genre de feux. Toutefois aux alentours des aérodromes et dans les zones de grand trafic aérien est-il pensable de supprimer le code de couleur des feux de navigation?

2) La perception des information colorées fournies au pilote par des instruments de bord.

   Au cours de vols de jour à grande altitude, le niveau de luminance très élevé dans le poste de pilotage ne permet plus au

pilote de lire les informations colorées autolumineuses fournies par ses instruments de bord, en particulier les informations fournies par les écrans de Radar, des collimateurs de pilotage etc.

Comment ce problème peut-il être résolu? En augmentant la luminance des informations? En obscurcissant la cabine?

Les Etats-Unis ont certainement trouvé une solution à ce problème au cours des nombreux vols dans l'espace qu'ils ont effectués au cours de ces dernières années. Ont-ils conservé le code de couleurs?

GRETHER Although colour filters do reduce the light intensity, and thus the possible viewing distance, this effect is not very great for broad-band red and green filters. Blue filters, on the other hand, cause a considerable loss in intensity and viewing distance.

With regard to cockpit lighting, many aircraft, including those of the USAF, use white instrument lighting, and there is apparently no difficulty in providing enough luminance for even the high altitude case. I am not familiar with the lighting in the Apollo space craft, but I am confident that adequate lighting of the instruments was provided.

GENERAL DISCUSSION

CULVER I would like to ask participants to give some thought to the problems of a screening test as well as a definitive test for colour vision, and to see if there is any possibility of an agreement on standardisation.

SIEGEL I am not involved with the military aspects of colour vision but I feel you might be interested in some of the experiences we have had in the Federal Aviation Administration. We require a 3rd class or private pilot to be able to recognize aviation red, green, and white. Our airline pilots have to have normal colour vision. We do have a considerable number of airline pilots flying with defective colour vision under the waiver clause and it is interesting that most of these are former military pilots. We allow examiners to use any one of the number of tests available, except the yarn test, but some of our older examiners still use the yarn test because they do not wish to buy the plates. We have 750,000 pilots and about 60,000 student pilots a year. We do not see nearly the number of colour defectives which we would expect to see if we apply the figure of 8%. If candidates fail the plate test we authorize a Farnsworth Lantern test, if one is available; if the lantern is not available or if they fail it, we given them a flight test or a practical test. For private pilots we merely take them to the end of the runway and the tower controller flashes the signal lantern. If they successfully identify the red, green and white we give them a waiver. If they fail in one or all the tests we still in effect give them a waiver since we then put on their certificate that it is not valid for night flying or colour signal control. We know that there is no way of enforcing this limitation and in any case we now have no airport controlled by colour signal lights. I also cannot recall anyone who could not fly a VASI approach even though he had defective colour vision. We have looked at our accident records for the last 5 years and can find no accidents directly attributable to defective colour vision. We are rapidly coming around to the point of view that colour vision should not be the subject of a clinical medical test but instead should be an operational test.

BAILEY I would like to make a comment that does not deal with colour vision but with the conspicuity of anti collision lights at long distances. Research work which we carried out recently with high intensity xenon flash lamps indicates that on helicopters and aircraft flying at low altitudes a certain limit of brightness cannot be exceeded because the tremendous back scatter which you get from the atmosphere, moisture, and dust etc. at these lower levels wipes out the entire scene in front of the cockpit. This limitation exists and is a problem.

PERDRIEL A cet égard, je pense qu'il serait intéressant, pour mieux apprécier les diverses modalités d'examen du sens chromatique qui nous ont été proposées, de confronter nos procédés au cours d'une prochaine réunion du Comité de vision de l'AGARD.

On pourrait alors réunir 10 sujets atteints de dyschromatopsie (examinés par les techniques les plus classiques) et les soumettre:

1) au test d'Ishihara et de Hardy-Rand-Rittler
2) aux difrérentes lanternes (Farnsworth, Beyne etc.)

Nous pourrions ainsi d'une manière précise étudier la valeur relative des différents procédés et juger ceux qui nous paraissent les plus efficaces.

BRENNAN I agree that the thing to do is to screen people with the Ishihara plates and then test them with the lantern. Obviously there are different lanterns, opinions of them vary, and some people are chauvinistic about their own lanterns. A study of the different testing methods will be very interesting particularly if, as I mentioned in my presentation, we simulate in the point source form those signal lights which are likely to be seen.

TREDICI I would like to point out that we have effectively already started on such a study since we have found deuteranopes who have already been subjected to a real life world of flying 3,000, 4,000 or 5,000 hours. We could bring them back and put them through the more artificial tests of determining their performance on the lantern and so add more people to the study. I agree with what has been said about initial screening, except that I disagree with the use of H-R-R plates. We have given them up and now use only the Ishihara because we found that the H-R-R plates would only screen out 75% of the abnormals. Thus anyone who passed the Ishihara plates could be considered normal, or at least 98% of them, and you would have no trouble with the 2%. What can we do with the others? We are using

the CTT and because of my loyalty I will continue with it, but I would not object to the Farnsworth Lantern because the United States Navy have about 15 years of experience with the Farnsworth Lantern. I would like to see if something can be done about either a retrospective study or an exchange of experiences. I think we will probably have to offer a compromise rather like the one I mentioned this morning, which is based on my clinical experience and what comes across my desk from TAC fighter, MAC etc. I think we should seek physiological perfection and cease arguing about how mild a defect can be accepted in our fighter pilots. This is difficult to do because one gets involved with personnel selection and the computers and the "'' ' but from information that is fed back to me these individuals ... ...ything they can get in the physiological realm which includes visual acuity, colour vision and all the other attributes. However, others who are flying MAC aircraft, transports, and similar aircraft could very easily be placed in a second category and thus we could still keep a large supply of pilots although without being able to put them into the fighter category. This might cause problems even amongst the pilots, but it is one of the ways I can see out of this dilemma.

I have had only two experiences to match Dr. Perdriel. One of them was the only pilot candidate I know who came and turned himself in for colour vision defect. He had passed his medical examination, he just slipped through, and had 60 hours flying. He did very well during the day, but when he commenced night flying he just could not see lights. He could not tell red from green and he could not fly formation. We examined him and he was a protanope so we grounded him. My only other experience was with one of the members of my staff who is a deuteranope. He said that he had no problems in driving his car, seeing the red light at 50 feet, or the tail lights of other vehicles, but when it began to rain and the windshield became desaturated and the other cues dropped down and the lights were at long distances he said he was lost; he really could not identify lights. We put him in an airplane together with another deuteranope and two normal observers. We went out three miles, the check was a "quick and dirty" type of experiment, and at 3 miles he and the other defective missed all the lights from the tower. At 2 miles they again missed all the lights from the tower. They did not begin to pick them up until they got within one mile range. So, for what it is worth, that has been my own experience.

CULVER Is there anyone in the audience who would advocate removing any standards for colour vision?

TAYLOR I have a few comments which go across the board. I will touch on every paper which I heard today. I would like to take these in a retrograde fashion and speak first on the subject of testing. It is a bad situation and we have had ample evidence that the testing devices which are currently in use are far from ideal. We have talked about competition between Ishihara plates, Hardy-Rand-Rittler plates, AOC plates and the Dvorine plates. I am not an expert in colour vision, but I have listened to the talks today and I know enough to know that it does not stop here, just talking about plates. In the first place it matters a great deal what edition of the Ishihara plates is in use. There is one good edition and the rest are substandard or not as good. It matters how they are stored, are they allowed to become faded, how much are they handled by the administrators of the test who may or may not be sensitive to the fact that these pigment plates are extremely delicate, extremely carefully balanced, and should not really be covered with thumb prints. It matters also that the test is performed with the correct illumination and not done by an open window with sunlight coming in, or in reflected sunlight from a brick wall; I have actually seen this done. With regard to the other tests I am horrified to say that a man came to me a few weeks ago who was not accepted for flight training in the Navy and when I asked him what test was administered he said the "Holmgren Wools"; so those are not dead but they will die, I hope. Colour vision testing is extremely critical and it is a very difficult and expensive problem to get everyone to one of the major centres. I feel that selection is very rarely done adequately at the source, that is in the various induction centres and recruitment centres around the United States. The question is what do we really want to test and how do we want to do it. I believe we want something which is expeditious and is likely to take 5 rather than 50 minutes. This probably eliminates some of the more sophisticated laboratory tests such as the Farnsworth Munsell 100 Hue, and certainly it eliminates the Wright Trichromatic Colormeter and very careful work with the anomaloscope which can really be more qualitative if it is carefully calibrated. For a quick test the plates are rapid, the lantern is superrapid. The lantern has, perhaps, a little more face validity in terms of operational tasks and this I think is what this meeting is all about. Surface colour tests or chips and plates also have their place. There is a test being developed by the United States

Navy which could be administered in 5 minutes. There have been constant references to the need for rapid testing without experimental error either on the part of the observer's responses or of the administrator of the test. The test to which I refer uses the electroretinal potentials and the electrooculogram. One simply puts 2 or 4 electrodes on the observer, puts him in a chair, shows him colours or forms, and you can then test things such as acuity, target motion and a variety of other visual functions simply by reading a polygraph. This is a neat method and its development is progressing. Another point is, are we really testing the appropriate things? Dr. Perdriel has brought up the fact that under stress, in this case auditory stress of 110 dB, there appears to be a decrement in visual function; but what was that decrement? If I remember correctly the decrement was in the visual fields but we are not testing the fields. Nothing was mentioned concerning the testing of peripheral colour vision and the angular extent of colour discrimination in the periphery. Intense noise has the effect of giving tunnel vision for colours and this aspect should be tested somehow. I think an important point to remember is that when we say we have no aircraft accidents, or really serious problems ascribable to colour defects, we lack definite proof. The accidents which we investigate where the man's colour vision was normal as tested tell us nothing; we cannot say anything about the restriction of fields. I submit that perhaps we are not testing the right things, and the things we are testing may or may not be done at present by appropriate tests.

WHITESIDE The granting of a number of waivers was referred to in the paper by Doctor Appleton. Where did the failures come from? Why were they not detected originally, or have they developed since the original examination? This appears time and time again and people are flying around with subnormal colour vision. What should we do?

APPLETON These people simply slipped through the net. They got on to flying status without having been detected, and they passed 1, 2 or 3 flight physicals because of inaccurate application of physical standards. Finally they are detected after they have been flying for 1,000, 2,000, 3,000 or 4,000 hours. At that stage they represent a significant investment on the part of their employer and that is why we go to so much trouble to assess them in the air. Now, the implicit comment is that these people should not have got through in the first place and I agree. But the fact is that they did and I suppose they will continue to do so in the future, because of the human error in the application of physical standards which has been with us since physical standard · 'nvented.

CULVER I think this is a ıown problem. There is, perhaps, a lack of adequate supervis training of the aeromedical technicians who administer the Isl plates. These plates seem to be the type most universally us ıd common faults include a failure to present them under the MacL the UK type of lighting, or a proper north light, and instead accepting inferior lighting or even light reflected from an outside brick wall. This is probably the reason that some people slipped through, or they may have had a very sympathetic technician that let them pass. That has been my experience.

WHITESIDE Obviously then, these people have adequately passed through the flying training and they have performed their task apparently without any difficulties. This is one of the points which has recurred throughout these presentations. No one has been able to show that specific failures have been associated with deficiences in colour vision; of course this may be difficult to determine in fatal accidents. The restricted fields associated with the noise factor have been mentioned but here we are dealing with combined stresses which is another, separate, topic. I think that at this stage we should limit ourselves to the very simple question of what type of test do we standardize on and what level of standardization should we seek? Another question stems from the granting by the FAA of waivers according to a pilot's experience and his type of flying. Thus the FAA specifies that such a pilot cannot fly a specific type of aircraft or fly under a specific set of meteorological conditions. Is this not part of the answer to using a wider spectrum of people who have colour anomalies but who, nevertheless, have experience; why reject them when they are doing the job? Why do we not broaden the standards if we have difficulty in getting aircrew candidates and say this pilot can fly in a specified role? This is similar to our approach to other medical standards.

CULVER I think that several speakers have alluded to this point and agree with you in principle. However, another good point which was raised earlier was the fact that sometimes in military flying you are in a difficult environment in which precision is a vital factor and at the same time there is a degradation of colours because of fog, smoke, a

multiplicity of tasks to be carried out and high noise levels. All this has to be taken into consideration and it becomes almost a philosophical question to set down physical standards. Much depends on how badly we need aircrew.

TREDICI As I said before, our problem would diminish by about 90% if we could select certain candidates for certain capabilities that they have. I have had recent interviews with our fighter people and they are adamant that they want to see both form objects and colour objects.

CULVER I would also like to point out that many of the pilots dealt with by the FAA are flying the type of aircraft which fly fairly low and fairly slow and are not as manoeuvrable as military aircraft. This is obviously not true of the commercial pilots; usually they have the advantage of having other crew with them and this is an added safety factor that the military pilot does not always enjoy.

LIDDY It is my impression that nearly all the delegates here have agreed that colour defectives can fly safely, that is those who pass lantern testing or a test of that type.

CULVER I would not say that they can all fly safely under all circumstances. I think that under certain circumstances they can fly safely, but there are limits.

LIDDY I refer to colour defective "safe" who can see, recognize a red signal, white signal and a green signal under decreased luminosity conditions.

CULVER Yes, if they could pass the lantern test they are acceptable.

I asked earlier if there was anyone who wanted to abolish colour vision standards and I did not get any response. I think we are agreed that we do want colour vision standards. We are also agreed that we would accept a candidate for flying if he passed one of the lantern tests.

PERDRIEL Une dernière question qui est donc pratique et qui rejoint un peu la préoccupation de Monsieur Whiteside. On nous a dit tout à l'heure effectivement que les différents tests à l'aptitude que nous avons passés permettent de catégoriser très en gros ceux qui ont une excellente vision des couleurs et ceux qui ont une vision des couleurs compatible avec la sécurité aérienne. Le problème est de pouvoir orienter justement ces élèves-pilotes ou ces élèves-navigateurs et même ces élèves-mécaniciens vers des spécialités. La question que je pose est celle-ci: Est-ce-que dans les différents pays les profils d'aptitude, en ce qui concerne le sens chromatique, qui sont nécessaires à telle spécialité pilote, navigateur, mécanicien sont établis directement par le commandement ou bien en accord avec un expert ophtalmologiste intéressé par le système des couleurs? Car je pense que la symbiose de travail entre les opérationnels, les navigants et, d'autre part, l'expert chargé du sens chromatique pourrait être beaucoup plus fructueuse que si la décision était prise unilatéralement. C'est ainsi par exemple que nous sommes tous d'accord, comme j'ai entendu avec plaisir Monsieur Tredici le mentionner, sur le fait que les élèves-pilotes doivent avoir un standard chromatique excellent. Eh bien, est-ce-que ce standard d'aptitude chromatique est défini, je le répète, par le commandement ou bien est-ce-que les médecins dans les différents pays ont un mot à dire.

CULVER I will try to answer that as best I can, at least for the United States. The standards are established by headquarters, supposedly with an input from the ophthalmologists. However, there are certain circumstances in which the advice of the ophthalmologists may not always be accepted and the headquarters may make the decision. This may not be true in other countries and I am only speaking for the United States.

WHITESIDE I always had the impression that visual standards resemble the grid of the electronic valve. The manning requirements alter the potential of the source to allow more candidates through according to the level of the requirements. For example, in wartime you lower the standards if you cannot get the candidates.

TREDICI I would like to clarify one further point. Acquired colour defects are really not a problem at all. You noted in my presentation that out of 4500 individuals only 5 had an acquired defect and in each case in one eye only. They had central serous retinopathy and this is a macular problem. Usually they have more severe symptoms than the effects on their colour vision. We discovered the colour vision disturbance because we were running a battery of scientific tests. It is usually the visual acuity which is reduced, and along with that they cannot recognize colour, most frequently blue. So this is not a problem at all in flying personnel. We only need to have colour

vision tested once on the original entrance, since it normally never changes again. Many of the individuals who were in my study did not have numerous examinations and all the colour defects found had either never been found by other examiners or they were allowed to slip through.

CULVER

It is particularly true that uner wartime conditions, when you are pushing great numbers through, they will be tested only once, but defects may show up later under a subsequent examination for another purpose. We are all agreed that we would not want to abandon completely the testing of colour vision, but there is definitely a need for a good screening test, such as the Ishihara, with the backup of a good lantern such as the Farnsworth, the CTT, or one of the new lanterns under development. These are matters we must look into in the future.